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Design and Simulation of Compressed Air Vehicle an Experimental Study

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Abstract: The latest trend in the automotive industry is to develop light weight vehicles. Every automotive industry is looking to reduce the weight of the vehicle as it helps in the better handling of the vehicle and increases the efficiency of the vehicle. Today, the heavy vehicles are known for producing a large amount of harmful gases like CO_2, SO etc. which act as the major source for global warming. So research is going on to find a light weight vehicle which does not pollute the environment. One of the alternatives is the use of compressed air to generate power to run an automobile. Due to the unique and environmental friendly properties of air, it is considered as one of the future fuels which will run the vehicles. In this paper, experimental analysis is done on prototype of compressed air vehicle. Different parameter like static nodal stress, static displacement, shape deformation, factor of safety is calculated.
Keywords: Compressed air, Static Nodal Stress, Static Displacement, Shape Deformation, Factor of Safety

I. INTRODUCTION

At first glance the idea of running an engine on air seems to be too good to be true. Actually, if we can make use of air as an aid for running an engine it is a fantastic idea. As we all know, air is all around us, it never runs out, it is non-polluting and it is free. An Air Driven Engine makes use of Compressed Air Technology for its operation. Compressed Air Technology is now widely preferred for research by different industries for developing different drives for different purposes. The Compressed Air Technology is quite simple. If we compress normal air into a cylinder the air would hold some energy within it. This energy can be utilized for useful purposes. When this compressed air expands, the energy is released to do work, so this energy in compressed air can also be utilized to displace a piston. This is the basic working principle of the Air Driven Engine. It uses the expansion of compressed air to drive the pistons of the engine. So an Air Driven Engine is basically a pneumatic actuator that creates useful work by expanding compressed air. This work provided by the air is utilized to supply power to the crankshaft of the engine.

In the case of an Air Driven Engine, there is no combustion taking place within the engine. So it is non-polluting and less dangerous. It requires lighter metal only since it does not have to withstand elevated temperatures. As there is no combustion taking place, there is no need for mixing fuel and air. Here compressed air is the fuel and it is directly fed into the piston cylinder arrangement. It simply expands inside the cylinder and does useful work on the piston. This work done on the piston provides sufficient power to the crankshaft.[1]

II. LITERATURE REVIEW

The first air powered vehicles were actually trains. The Mekarski air engine, the Robert Hardie air engine and the Hoadley-Knight pneumatic system were used in the 1800's to power locomotives.In 1925, an article appeared in the Decatur Review about a man named Louis C. Kiser who converted his gasoline powered car to run on air. Lee Barton Williams in 1926 claimed to have invented the first air car.[2]

Over the recent decades, the serious environmental issues, such as greenhouse effect, ozone layer depletion and fog and haze, have drawn considerable attention. Burning of fossil fuels has been considered as the main cause of some serious environment issues. With respect to environmental protection, the issue of energy expenditure was emphasized. Some scholars consider that the petroleum crisis will happen, which may result inending the era of low-cost petroleum and develop the fierce competition market of the new energy automobiles.[3]

So far, the new energy automobiles, such as electric vehicles, hybrid electric vehicles, pneumatic power vehicles, gradually appear. The typical products of zero-pollution vehicles contain the electric vehicles, while there aretoxic elements within batteries which could spew toxic fumes. Morita discussed the growing modes of the power systems of future transportations. Negre*et al.*has developed a dual energy engine employing the petroland compressed air, and the relevant research is ongoing. The Moteur Development International (MDI) hasdeveloped a compressed air vehicle, namely, E.Volution . The air tank at the bottom of E.Volution can hold300 liters of compressed air, which can provide vehicle kinetic energy. The vehicle can travel 200 km at the

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speed of 96 km/h. And the virtue of the E.Volution is the charging process which just needs 3 minutes via a high-pressure air-charging station.[3]

In Europe inventors have made a simple air engine, thus opening a new field for compressed air car technology. These engines allow cars to run on compressed air instead of fuel. The air, super compressed and powerful, pumps the pistons in the car instead of small gas explosions. Pumping air instead of exploding gasoline means these cars have zero emission motors–no pollution, no oil. Inaddition, current average family cost of fuel is 60 dollars a week and half that for a hybrid car. The new air engines will give a whole week of driving for a few dollars. The company, MDI plans to sell this clean fuel vehicle and a compressed air hybrid in Europe for less than 15,000 dollars in near future.

Another inventor in Uzbekistan has modified a car to run it with compressed air, stored in a tank and claims that as the car runs, it will take in air and store it in the tank at pressure, resulting in a perpetual motion machine. Perpetual motion machines are, of course, not possible under the known laws of physics but the idea is not being dismissed as crank. The concept of compressed air being regenerated while the car is in motion is intriguing. It is akin to batteries of electric vehicles using regenerative charging and even a part regeneration of compressed air would be an advance from the present understanding of the technology.

An inventor in California (USA) has made a car running on compressed air, stored in scuba diving tanks. He modified an engine used on the Honda RC51 998 cc Superbike. He blocked off one of the cylinders of the engine and used the spark plug hole on the other cylinder to feed the compressed air. The compressed air drives the piston down as the power stroke. At the end of the power stroke, the compressed air is released through the exhaust valves and the exhaust is only air. The pistons were connected to the wheels through the Honda bike's six-speed transmission. This modified engine was mounted on a tubular frame and a body that looked like a curious crossbreed of a motorbike with a racing car.

A bank of three scuba tanks was used to store compressed air at 3500 psi and throttled it to 250 psi at the engine inlet with a self-designed throttle valve, linked to the accelerator pedal. The three tanks were sufficient for the test run over the 2 mile, where an average speed of 46.723 mph was achieved with a top speed of 54.058 mph. Further, a speed to the level of 300 mph is expected with compressed air. However, several issues like large size and heavy model due to the use of a number of tanks still remain before this concept can translate into a usable idea.

Tata Motors, India, as of January 2009 had planned to launch a car with an MDI compressed air engine in 2011. In December 2009 Tata's vice president of engineering systems confirmed that the limited range and low engine temperatures were causing problems. Tata Motors announced in May 2012 that they have assessed the design passing phase 1, the "proof of the technical concept" towards full production for the Indian market. Tata has moved onto phase 2, "completing detailed development of the compressed air engine into specific vehicle and stationary applications".[4]

A. Advantages

1) It uses no gasoline or other bio-carbon based fuel.
2) Compressed air engines reduce the cost of vehicle production because there is no need to build a cooling system, spark plugs or starter motor
3) Reduction or elimination of hazardous chemicals such as gasoline or battery acids/metals.
4) Pollution free and easy to manufacture.
5) Very low cost and fuel efficient (compressed air).
6) Low maintenance cost.

B. Disadvantages

1) Limited storage capacities of the compressed air tank
2) A tank containing 30MPA compressed air is risky and dangerous.
3) Low boot space, as compressed air car, will be having a compressed air tank
4) Running the vehicle on compressed air will be requiring the provision for filling the compressed air in the tank.

III. EXPERIMENTAL METHODOLOGY

Improvements in structural components design are often achieved on a trial-and-error basis guided by the designer know-how. Despite the designer experience must remain a fundamental aspect in design, such an approach is likely to allow only marginal

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product enhancements. A different turn of mind that could boost structural design is needed and could be given by structural optimization methods. For this various analysis is done on the frame of the compressed air vehicle which can be stated as follows: These methods are further discussed as follows.

A. Static Nodal Stress(Von Mises)

Stress or static analysis calculates the displacements, strains, and stresses in a part based on material, fixtures, and loads. A material fails when the stress reaches a certain level. Different materials fail at different stress levels. the von Mises stress has no direction. It is fully defined by magnitude with stress units. The von Mises stress is used by failure criteria to assess failure of ductile materials. The von Mises stress is used to predict yielding of materials under any loading condition from results of simple uniaxial tensile tests. The von Mises stress satisfies the property that two stress states with equal distortion energy have equal von Mises stress Mathematically the von Mises yield criterion is expressed as:

$$J_2 = k^2$$

where k is the yield stress of the material in pure shear and J_2 is the second deviatoric stress invariant . Simplified von Mises equation

$$\sigma_v = \sqrt{\frac{1}{2}[(\sigma_{11}-\sigma_{22})^2+(\sigma_{22}-\sigma_{33})^2+(\sigma_{33}-\sigma_{11})^2+6(\sigma_{12}^2+\sigma_{23}^2+\sigma_{31}^2)]}$$

Where σ_v is the von Mises stress[5]

B. Static Displacement(Resultant Displacement)

Deformation in continuum mechanics is the transformation of a body from a reference configuration to a current configuration. Strain is a description of deformation in terms of relative displacement of particles in the body that excludes rigid-body motions. The resultant displacement in static analysis is obtained from the value of strain on the material as inferred from the stress on the body and the material used to obtain it. The equation of displacement as inferred from Hooke's Law is

$$\Delta l = \frac{Pl}{AE}$$

Where Δl represents the displacement, P is the force acting on it and E is the Young's modulus of elasticity of the material.[6]

C. Shape Deformation

In materials science, deformation refers to any changes in the shape or size of an object due to an applied force (the deformation energy in this case is transferred through work). Strain is a measure of deformation representing the displacement between particles in the body relative to a reference length.A general deformation of a body can be expressed in the form **x** = ***F***(**X**) where **X** is the reference position of material points in the body. Such a measure does not distinguish between rigid body motions (translations and rotations) and changes in shape (and size) of the body. A deformation has units of length. The equation for strain is

$$\varepsilon = \frac{L-l}{L}$$

Where ε is the strain, L is the original dimension and l is the final dimension after application of stress.[7]

D. Factor of Safety(Max Von Mises Stress)

Use of the von Mises Criterion as a failure theory is only exactly applicable when homogeneous material properties are equal to

$$\frac{F_{sy}}{F_{ty}} = \frac{1}{\sqrt{3}} = 0.577$$

Since no material will have this ratio precisely, in practice it is necessary to use engineering judgement to decide what failure theory is appropriate for a given material. Alternately, for use of the Tresca Theory, the same ratio is defined as 1/2. The yield Margin of safety is written as

$$MS_{yld} = \frac{F_y}{\sigma_v} - 1$$

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Although the given criterion is based on a yield phenomenon, extensive testing has shown that use of a "von Mises" stress is applicable at ultimate loading. [8]

$$MS_{ult} = \frac{F_u}{\sigma_v} - 1$$

IV. RESULT

The following figure is the isometric view of the compressed air vehicle.

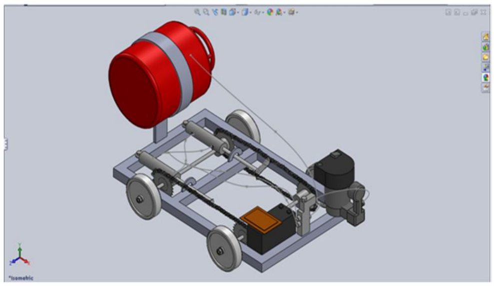

Figure 1 Isometric view of compressed air vehicle

The figure that follows is the isometric view of the frame of the compressed air vehicle. This frame is constructed of mild steel.

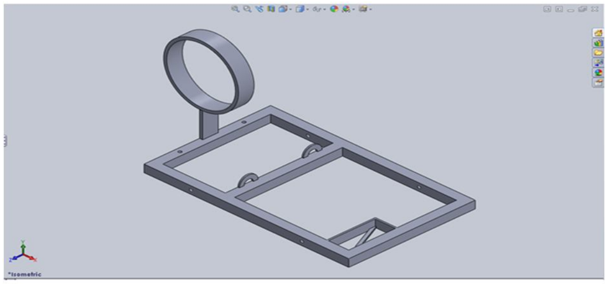

Figure 2 Isometric view of frame of the compressed air vehicle

The analysis done on the frame based on the stresses it is subjected to is as follows.

A. Static Nodal Stress(Von Mises)

The following figure indicates the nodal stress that the frame bears. The deformation scale is of 6167.4:1 to clearly indicate the deformation in an exaggerated manner. It is calculated using the von Mises criterion. In the figure the color coding indicates the amount if stress the frame undergoes in comparison to the rest of its body. Blue indicates minimal stress(below 916.88kN/m^2) , green indicates stress levels higher than that indicated by blue color(1604.54 to916.88kN/m^2), stress indicated by yellow color is higher then green(2292.21 to1604.5488kN/m^2) and red color indicated the maximum stress borne by the frame(above 2292.21kN/m^2).

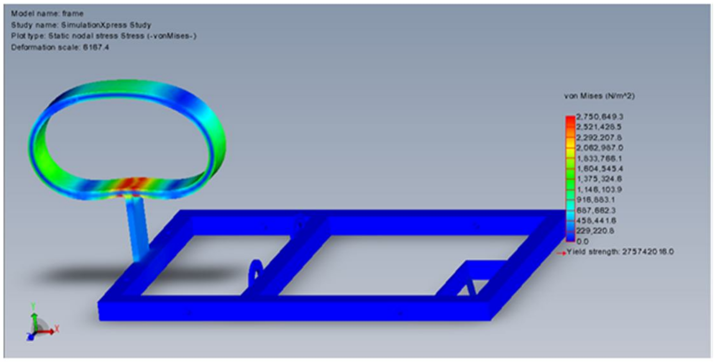

Figure 3 Static nodal stress(von Mises)analysis of the frame

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B. Static Displacement(Resultant Displacement)

The following figure indicates the resultant displacement that the frame bears. The deformation scale is of 6167.4:1 to clearly indicate the deformation in an exaggerated manner. It's calculated using the equation indicated by the Hook's Law. In the figure the color coding indicates the amount if static displacement occurring in the frame in comparison to the rest of its body.

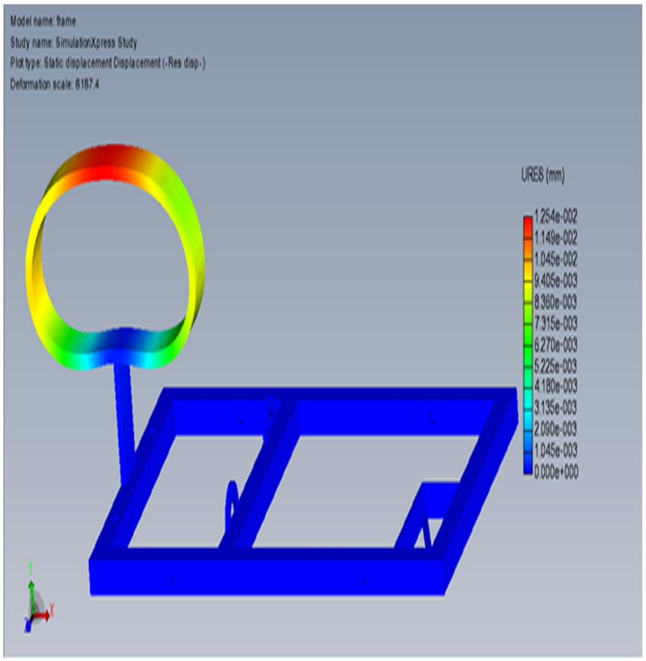

Figure 4 Static displacement analysis of the frame

C. Shape Deformation

The following figure simply indicates the shape deformation of that the frame. The deformation scale is of 6167.4:1 to clearly indicate the deformation in an exaggerated manner. Its calculated using the equation indicated by the equation for strain.

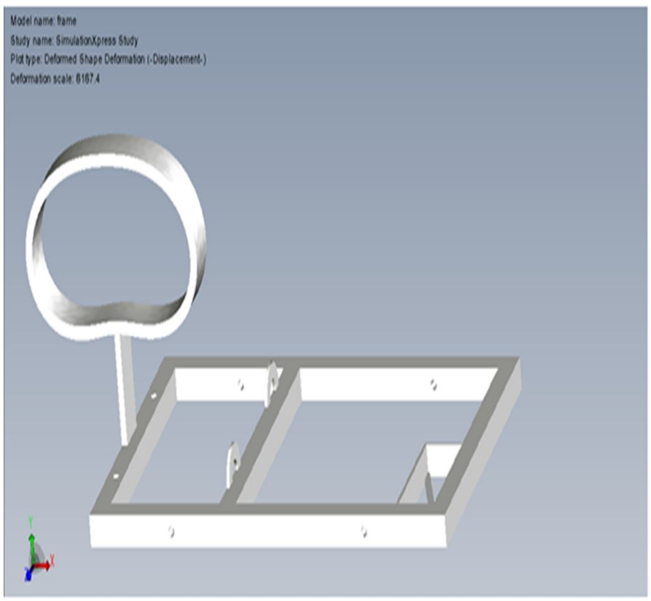

Figure 5 Shape deformation analysis of the frame

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D. Factor of Safety(Max Von Mises Stress)

The following figure indicates the conformance of the frame with the factor of safety as calculated using the von Mises criterion. Since there is no deformation indicated and the entire structure is indicated in blue color, it indicates that our design is well within the safety standards as calculated using the von Misescriterion.

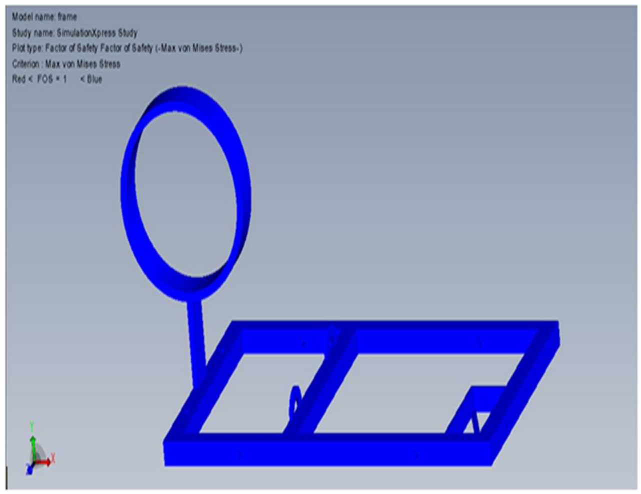

Figure 6 Factor of safety(max vonMises stress)analysis of the frame

An overview has been given on the need of structural analysis of the frame of the compressed air vehicle and the types of analysis that can be done to determine the feasibility and soundness of the design based on the material of the frame. These techniques also give us an idea of the region that requires our attention for making changes to increase the structural strength along with reduction of cost. The factor of safety analysis indicates that our design is well within the factor of safety as indicated by the maximum von Mises stress and hence our design is safe for usage.

V. CONCLUSION

Even though the vehicle is in early stage of development, it holds a lot of promise and provides scope for further research. Thus we designed the vehicle model which is eco friendly and does not cause pollution like internal combustion engines. This vehicle will help in reducing the problem of global warming since internal combustion engines contribute to the problem the most. It uses non-conventional energy source i.e. atmospheric air. This will help to save the non renewable sources of energy. So, the successful policy for the 21st century will depend on the non conventional sources. Pneumatic vehicle can prove solution to depleting natural resources and can be the technology of tomorrow. In this project a model of pneumatic vehicle is designed.

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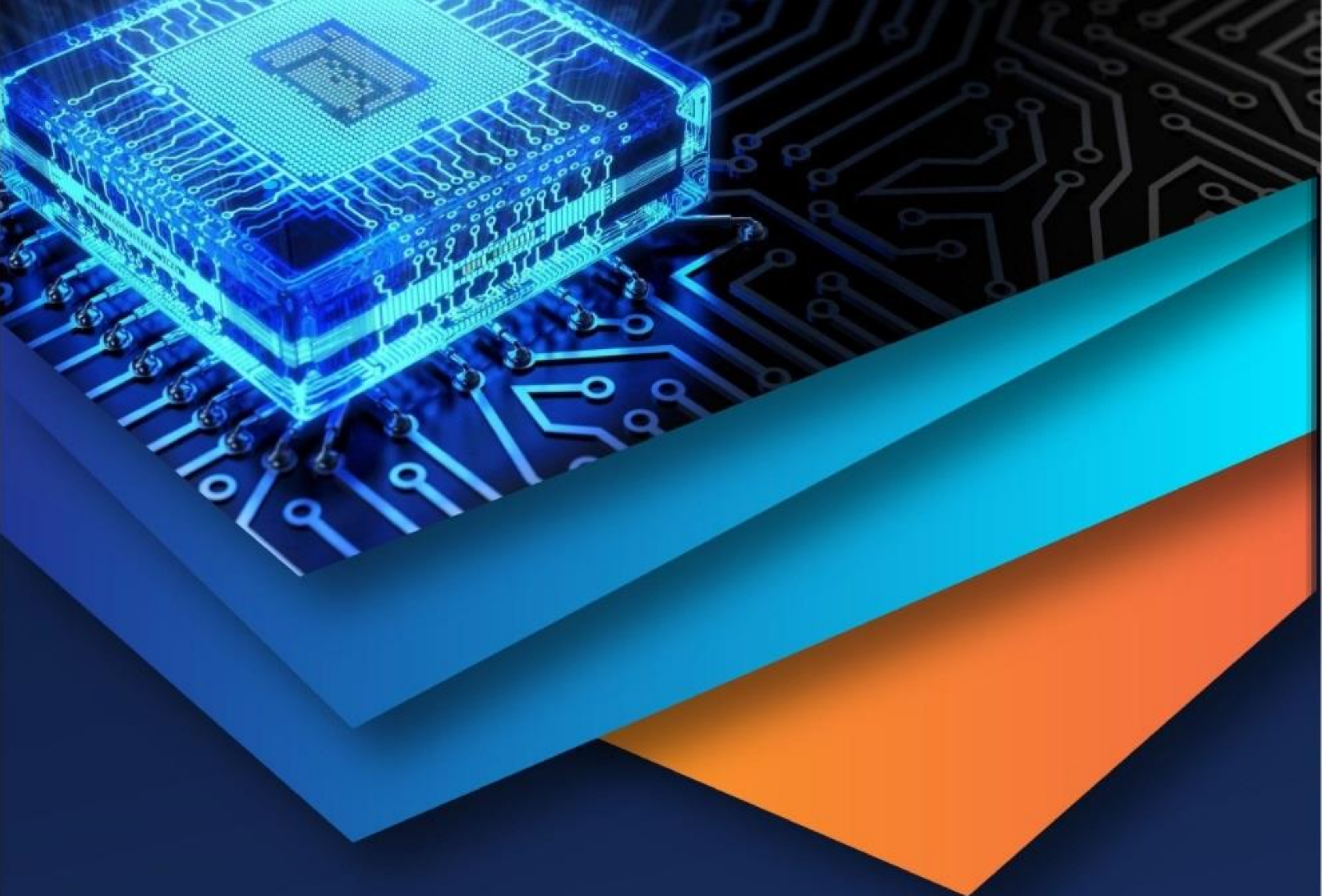

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