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Analysis the Influence of Pressure Distribution on Exhaust Manifold Using FEM

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Abstract: In this paper the 3D model of the exhaust manifold was realized using Autodesk Inventor Professional 2024 and finite element analysis was performed, in order to determine the state of stress and deformation, by applying restrictions and loads conditions. The materials chosen, for exhaust manifold, was in accordance with the specialized literature. The materials taken for static analysis was Stainless Steel 440C and Iron Gray Cast. Following the comparative study for the two models, it can be specified that the importance of the material for the construction of the exhaust manifold depends on the mass properties and their design.
Keywords: Exhaust manifold, Solid modeling, Static analysis, Autodesk Inventor

I. INTRODUCTION

The exhaust manifold is the first part of the vehicle's exhaust system, it connects to the engine and records the emissions of the engine in operation. The exhaust manifold receives the air-fuel mixture from several cylinders of the vehicle's engine. The exhaust manifold receives all of the engine's burned gases, but also uses very high temperatures to completely burn the unused or incompletely burned gas. The distributor has the first oxygen sensor in the exhaust system to check the amount of oxygen entering the system. The oxygen sensor monitors the amount of oxygen and tells the fuel injection system to increase or decrease the amount of oxygen in the mixture used to feed the engine. Basically, the exhaust manifold acts as a funnel and is used to collect all the engine emissions. When they are in one place and burned completely, the collector directs the emissions to the rest of the exhaust system [1].

The principle of the exhaust manifold explains that it is designed to avoid overlapping exhaust strokes as much as possible, thus keeping back pressure to a minimum. This is often done by splitting the exhaust manifold into two or more branches so that two cylinders not to burn out in the same branch at the same time [2].

The pressure inside the gallery is between 100 kPa and 500 kPa and the temperature is used to exhaust the collector, which will lead to thermo-mechanical failure [3]. Back pressure is created due to the exhaust system not being completely released before the gases from the other cylinder are released. These gas pressure waves restrict the engine's true performance possibilities. The modelling strategy developed in many studies consists in separated thermal and mechanical simulations, performed using the Finite Element Analysis.

V. Hugar [4] presents an analysis to investigate stresses for different scenarios when Structural Steel and Aluminium Alloy materials was used for exhaust manifold and he utilized ABAQUS software for the Finite Element Analysis. The results suggest the suitable material for the manifold is Structural Steel.

II. EXHAUST MANIFOLD DESIGN

Solid modelling of the exhaust manifold was done using Autodesk Inventor, version 2023 with the literature data and the solid model of the exhaust manifold are shown in Fig. 1.

Fig. 1 Exhaust manifold design

III. STATIC ANALYSIS

The exhaust gallery has the role of taking over the exhaust gases from the engine, taking over, at the same time, a large part of the heat generated by the engine compartment. As a rule, the exhaust galleries are made of cast iron, being built in such a way as to ensure an efficient thermal insulation, because the emitted exhaust gases have a temperature of almost 8000 C, and the pressures inside the gallery are between 100 kPa and 500 kPa, which leads to thermo-mechanical failures.

A. Choosing Material

The paper compares the values obtained for two materials used in the construction of the exhaust manifold: Stainless Steel 440C and Iron Gray Cast, in accordance with [5], [6]. Materials and their properties are shown in Table 1.

TABLE I
MATERIAL PROPERTIES

Parameters	*Stainless Steel 440C*	*Iron Gray Cast*
Young's Modulus [MPa]		
Poisson's Ratio	206700	120500
Shear Modulus [MPa]	0.27	0.3
Mass Density [Ns^2/mm^4]	83900	58100
Tensile Strength [MPa]	7.75E-09	7.15E-09
Yield Strength [MPa]	861.250	884
Thermal Expansion	689	758
Coefficient	1.04E-05	1.2E-05
Thermal Conductivity N/(sec	2.423E+01	2.1E+01
^oC)	4.6E+08	4.5E+08
Specific Heat $mm^2/(sec^2\ ^oC)$		

B. The Restrictions and Load Condition

Restrictions have been imposed on the connection flange of the exhaust gallery, as show in Fig. 2. Applied requests were made according to the specialized literature. A constant pressure was applied inside the gallery. Two values were imposed for the pressure inside the gallery, 200kPa and 500kPa, knowing that the pressure takes values in the range of 200 kPa...500 kPa [9].

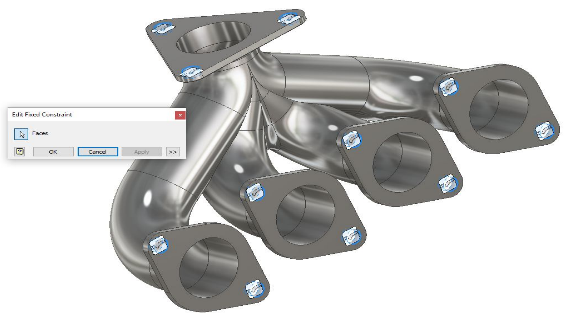

Fig. 2 Restrictions condition

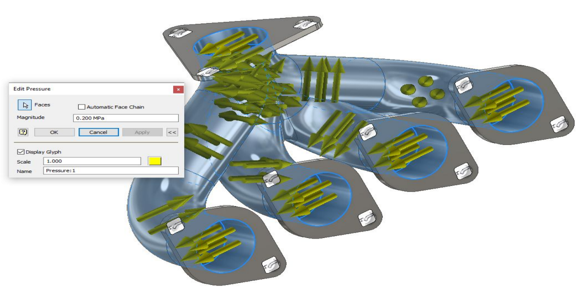

Fig. 3 Load condition

C. Generate Meshing

To generate the mesh, the automatic generation mode was used with parabolic element order, the model being meshed into 38418 elements and 75789 nodes, Fig. 4.

Fig. 4 Exhaust gallery meshing

D. Static Analysis Results

1) Iron Gray Cast Results

Following the FEM analysis, for the Iron Gray Cast, the following values were recorded: for the Von Mises stresses, the maximum value was 129.2 MPa, at the internal pressure of 200 kPa, Fig. 5 and 323 MPa for 500 kPa internal pressure, Fig. 6.

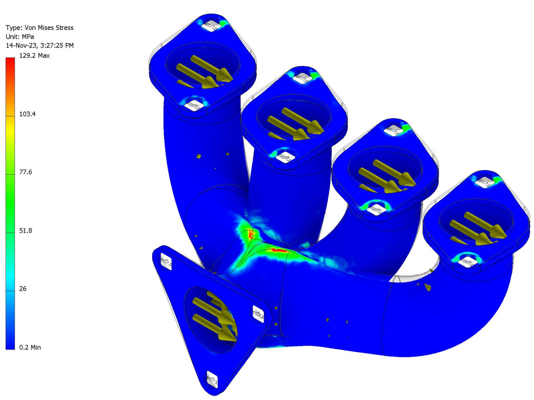

Fig. 5 Von Mises stress – Iron Gray Cast - 200 kPa pressure

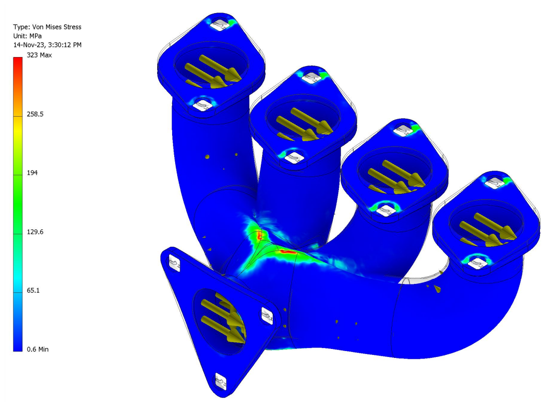

Fig. 6 Von Mises stress – Iron Gray Cast - 500 kPa pressure

The maximum value of the total deformation was 0.3404 mm, for the internal pressure of 200 kPa, Fig. 7 and 0.8509 mm for 500 kPa internal pressure, Fig. 8.

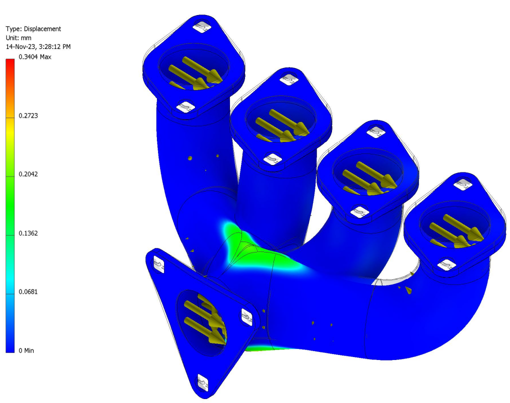

Fig. 7 Deformation – Iron Gray Cast - 200 kPa pressure

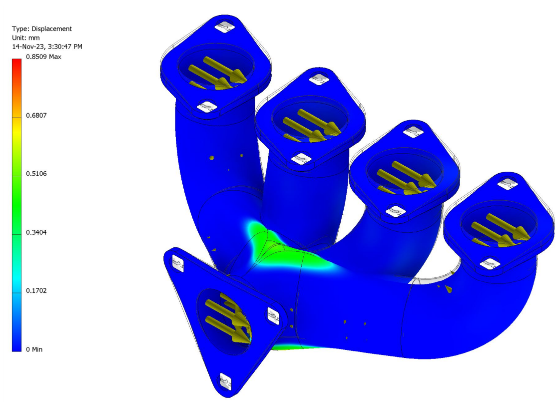

Fig. 8 Deformation – Iron Gray Cast - 500 kPa pressure

The minimum value of the safety factor was 5.87, at an internal pressure of 200 kPa, Fig. 9 and 2.35 for 500 kPa internal pressure, Fig. 10.

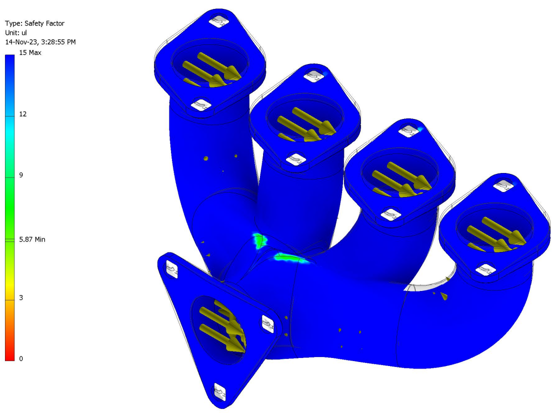

Fig. 9 Safety factor – Iron Gray Cast - 200 kPa pressure

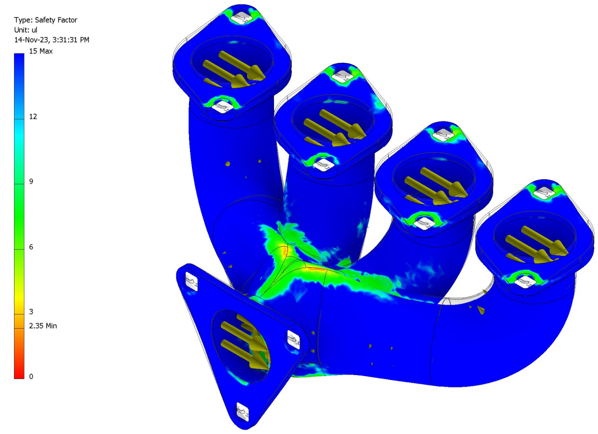

Fig. 10 Safety factor – Iron Gray Cast - 500 kPa pressure

2) Stainless Steel 440C Results

Following the FEM analysis, for the Stainless Steel 440C, the following values were recorded: for the Von Mises stresses, the maximum value was 130.1 MPa, at the internal pressure of 200 kPa, Fig. 11 and 3225.3 MPa for 500 kPa internal pressure, Fig. 12.

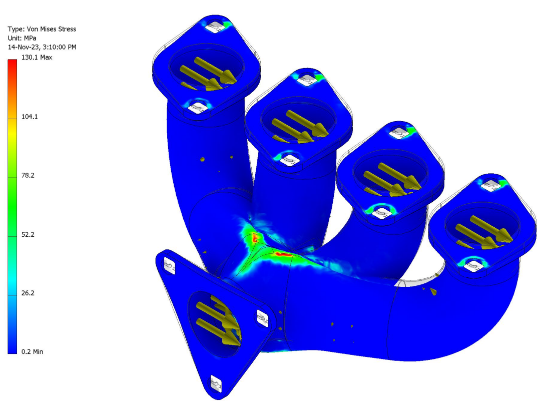

Fig. 11 Von Mises stress – Stainless Steel 440C - 200 kPa pressure

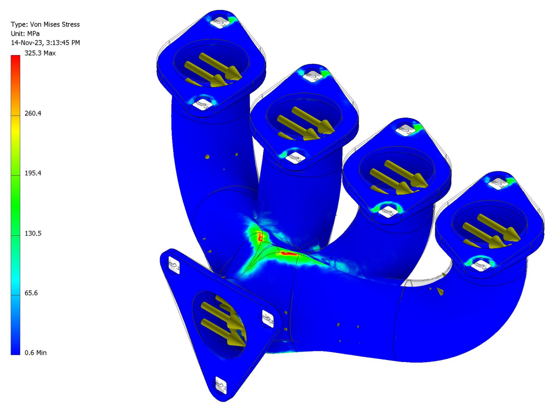

Fig. 12 Von Mises stress – Stainless Steel 440C - 500 kPa pressure

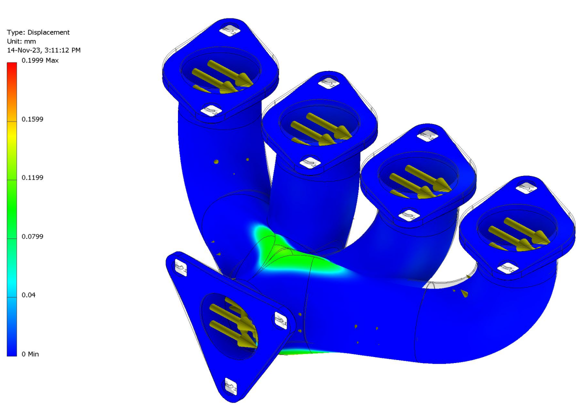

Fig. 13 Deformation – Stainless Steel 440C - 200 kPa pressure

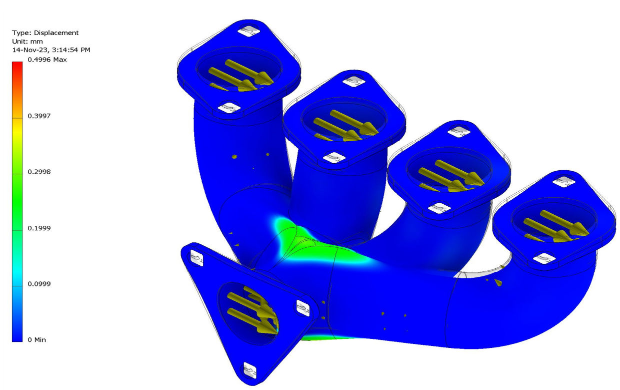

Fig. 14 Deformation – Stainless Steel 440C - 500 kPa pressure

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The maximum value of the total deformation was 0.1999 mm, for the internal pressure of 200 kPa, Fig. 13 and 0.4996 mm for 500 kPa internal pressure, Fig. 14.

The minimum value of the safety factor was 5.29, at an internal pressure of 200 kPa, Fig. 15 and 2.12 for 500 kPa internal pressure, Fig. 16.

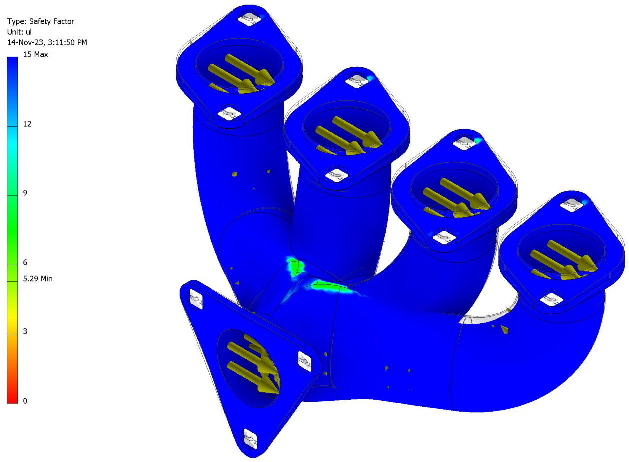

Fig. 15 Safety factor – Stainless Steel 440C - 200 kPa pressure

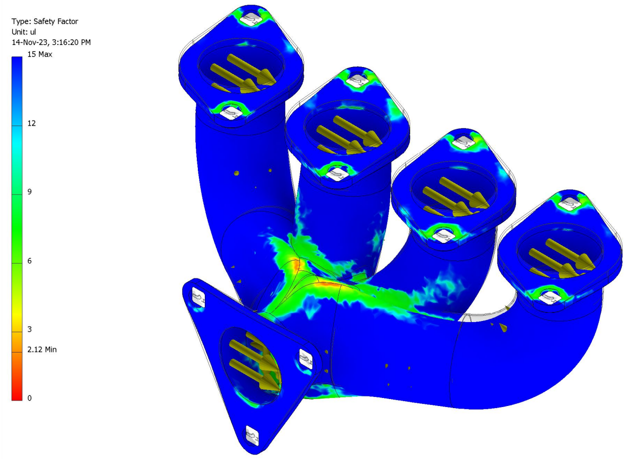

Fig. 16 Safety factor – Stainless Steel 440C - 500 kPa pressure

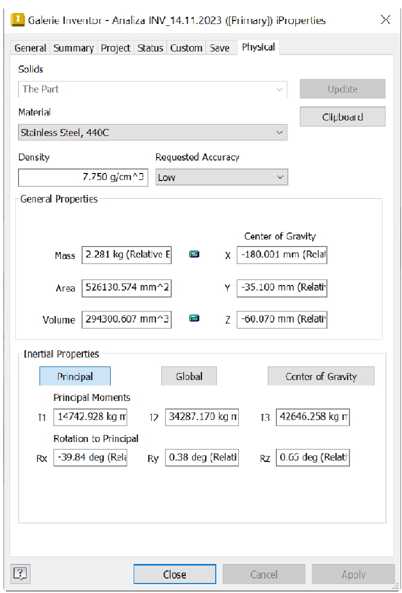

Fig. 17 Physical properties - Stainless Steel 440C

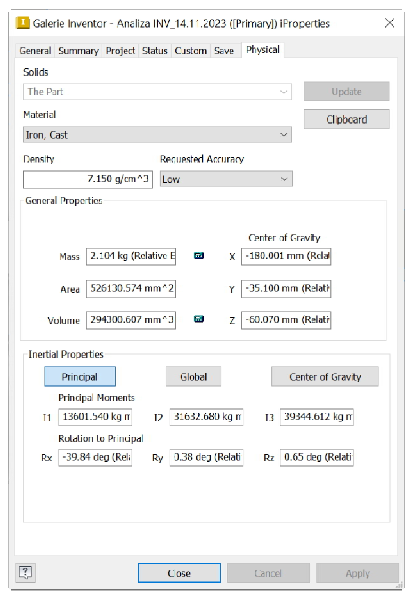

Fig. 18 Physical properties - Iron Gray Cast

After solid modelling of the exhaust gallery and assigning the material, the values for its weight were also obtained. The weight of the Iron Gray Cast exhaust gallery was 2.104 kg and the weight of Stainless Steel 440 C exhaust gallery was 2.281 kg.

In the following Fig. 17 - 18 are presented the information related to the general characteristics, mass and inertia for exhaust gallery models analyzed.

IV. CONCLUSION

The scope of this paper was to carry out a study of the behavior under the action of pressure of a exhaust gallery. In order to determine the state of stresses and deformations, the 3D models of the exhaust gallery were made with the help of the Autodesk Inventor Professional 2024.

After running the static analysis, the maximum values of the Von Mises stress were recorded for Stainless Steel 440 C exhaust gallery when a pressure of 500 kPa was applied and the maximum values of the deformations it was obtained for Iron Gray Cast at the same pressure.

Following the comparative study for the models, it can be specified that the importance of the material for the construction of the exhaust gallery depends on the mass properties and their design.

The study can be continued with a more complex analysis by using other materials under the same stress conditions and by studying thermal analysis of the exhaust gallery.

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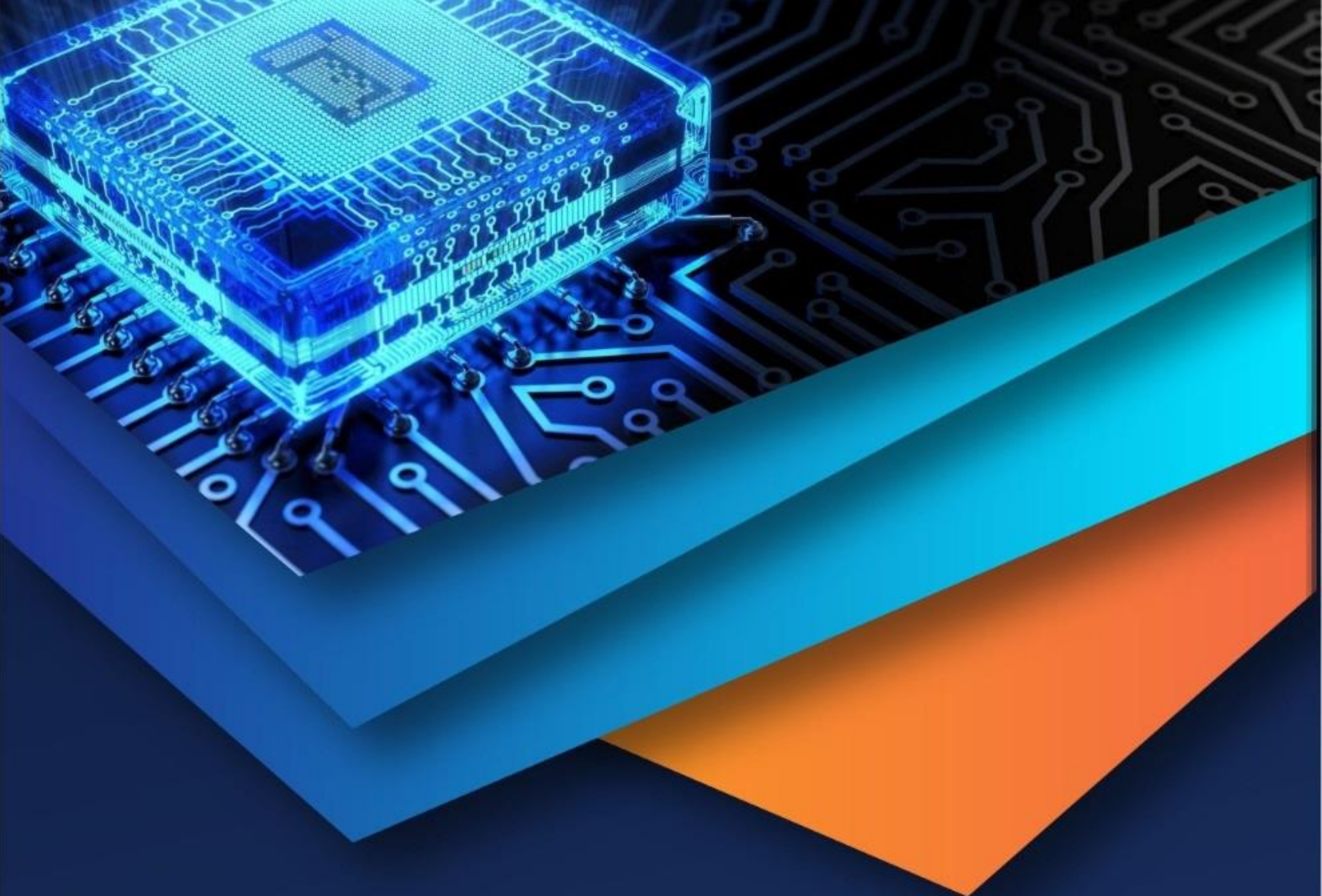

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