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Smart Braking System Using Pneumatic Bumper

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Abstract: Road accidents are one of the major causes of injuries and loss of life across the world. Many accidents occur due to delayed driver reaction, lack of attention, or sudden obstacles appearing in front of the vehicle. To reduce the severity of such accidents and improve vehicle safety, an automated safety mechanism called the Smart Braking System with Pneumatic Bumper is proposed. This system is designed to detect obstacles in front of a vehicle and automatically activate braking while simultaneously extending a pneumatic bumper to absorb impact energy. The proposed system mainly consists of distance sensors (ultrasonic or infrared sensors), a microcontroller control unit, pneumatic cylinders, solenoid valves, and a compressed air reservoir. The sensors continuously monitor the distance between the vehicle and any obstacle ahead. When an object is detected within a predefined critical distance, the sensor sends a signal to the microcontroller. The microcontroller processes this information and immediately activates the braking system to reduce the vehicle speed. At the same time, the system triggers a solenoid valve, allowing compressed air from the air tank to flow into the pneumatic cylinder. This action forces the piston to extend outward, pushing the pneumatic bumper forward. The extended bumper acts as a cushioning device that absorbs a portion of the collision energy, thereby reducing the damage to the vehicle and minimizing the impact force experienced by passengers. The integration of automatic braking and pneumatic impact protection provides a dual safety mechanism. While the braking system attempts to stop or slow down the vehicle, the pneumatic bumper prepares to absorb any remaining impact if a collision occurs. This combined approach significantly improves vehicle safety, especially during low and medium speed accidents. The proposed system is cost-effective, reliable, and easy to implement, as it uses commonly available electronic and pneumatic components. It can be applied in automobiles, public transport vehicles, and industrial vehicles where collision prevention and passenger safety are important. Therefore, the Smart Braking System with Pneumatic Bumper offers a practical solution to enhance road safety and reduce accident-related damages

I. INTRODUCTION

A. Background Information of the Study

Road transportation plays an essential role in modern society, but it also comes with serious safety challenges. The rapid increase in the number of vehicles on the road has led to a significant rise in traffic accidents worldwide. Many of these accidents occur due to delayed driver reaction, lack of concentration, sudden obstacles, poor visibility, or unexpected traffic conditions. In many cases, even a delay of a few seconds in applying the brakes can result in severe collisions, causing damage to vehicles and serious injuries to passengers.

To address this issue, modern vehicle safety systems are being developed to assist drivers and reduce the chances of accidents. One such advancement is the *Smart Braking System with Pneumatic Bumper, which is designed to automatically detect obstacles and activate safety mechanisms faster than human reflexes. This system combines **sensor technology, electronic control systems, and pneumatic actuation* to improve vehicle safety and minimize collision damage.

The smart braking system works by continuously monitoring the distance between the vehicle and objects in front of it using *ultrasonic or infrared sensors. These sensors send signals that help determine the distance to nearby obstacles. When the system detects that an obstacle is within a dangerous or predefined safety range, the sensor sends a signal to a **microcontroller*, which acts as the control unit of the system. The microcontroller processes the sensor data and immediately activates the braking mechanism. In addition to automatic braking, the system also uses a *pneumatic bumper* to reduce the impact force during a collision. The pneumatic bumper operates using compressed air stored in a tank. When the microcontroller receives a signal from the sensor indicating a possible collision, it activates a *solenoid valve* that releases compressed air into a *pneumatic cylinder*. This causes the piston in the cylinder to move forward, extending the bumper outward from the vehicle. The extended bumper acts as a shock absorber that helps reduce the damage caused by the impact.

The integration of automatic braking and pneumatic impact absorption creates a *dual protection system*. The braking system reduces the vehicle speed to prevent or minimize the collision, while the pneumatic bumper absorbs the remaining impact energy if a collision occurs. This combination improves passenger safety and reduces damage to the vehicle body.

Another advantage of this system is that it is *simple, cost-effective, and easy to install* compared to many advanced safety technologies used in modern vehicles. The components used in the system, such as sensors, microcontrollers, pneumatic cylinders, and solenoid valves, are commonly available and require minimal maintenance. Because of this, the system can be implemented not only in cars but also in buses, trucks, and industrial vehicles.

Therefore, the *Smart Braking System with Pneumatic Bumper* is an innovative approach to improving vehicle safety by reducing driver dependency and providing an automatic response during emergency situations. By detecting obstacles early and activating braking and impact protection systems, this technology can significantly reduce the severity of road accidents and enhance overall transportation safety.

II. METHODOLOGY

The methodology of the Smart Braking System using Pneumatic Bumper describes the systematic process used to design, develop, and operate the system for improving vehicle safety. The main aim of this system is to detect obstacles in front of the vehicle, automatically apply the braking system, and activate a pneumatic bumper to reduce the impact during collisions. The methodology involves several stages such as sensing, signal processing, pneumatic actuation, and braking action.

A. System Design

The first step in the methodology is designing the complete system structure. The system is designed by integrating different components such as sensors, a control unit, a compressor, a solenoid valve, a pneumatic cylinder, and a bumper mechanism. Each component is arranged in such a way that it works together to provide automatic braking and impact protection.

B. Obstacle Detection

The obstacle detection stage is carried out using sensors such as infrared (IR) sensors or ultrasonic sensors. These sensors are installed at the front portion of the vehicle. They continuously monitor the distance between the vehicle and any object present on the road. When the sensor detects an obstacle within a certain safety distance, it generates an electrical signal.

C. Signal Transmission to Control Unit

Once the obstacle is detected, the signal generated by the sensor is transmitted to the control unit or microcontroller. The control unit acts as the brain of the system. It receives the input signal from the sensor and processes the information to determine whether the braking system and pneumatic bumper should be activated.

D. Decision and Control Operation

The control unit analyzes the distance between the vehicle and the obstacle. If the distance is below the predefined safety limit, the controller sends an output signal to activate the braking system and the pneumatic mechanism. This ensures that the system responds quickly to avoid or reduce the severity of an accident.

E. Activation of Solenoid Valve

After receiving the signal from the control unit, the solenoid valve is activated. The solenoid valve controls the flow of compressed air from the air compressor to the pneumatic cylinder. It acts as a switching device that opens or closes the air passage based on the signal from the controller.

F. Pneumatic Cylinder Operation

When the solenoid valve opens, compressed air enters the pneumatic cylinder. The air pressure pushes the piston inside the cylinder forward. This linear motion of the piston is used to extend the bumper outward from the front of the vehicle.

G. Bumper Extension Mechanism

The pneumatic cylinder is connected to a specially designed bumper mechanism. When the piston moves forward, the bumper moves outward and forms a protective barrier in front of the vehicle. This bumper absorbs a portion of the collision energy and reduces the impact force during a crash.

H. Automatic Braking Action

At the same time, the braking system of the vehicle is automatically applied. The automatic braking reduces the speed of the vehicle or completely stops it before the collision occurs. This action significantly reduces the severity of the accident.

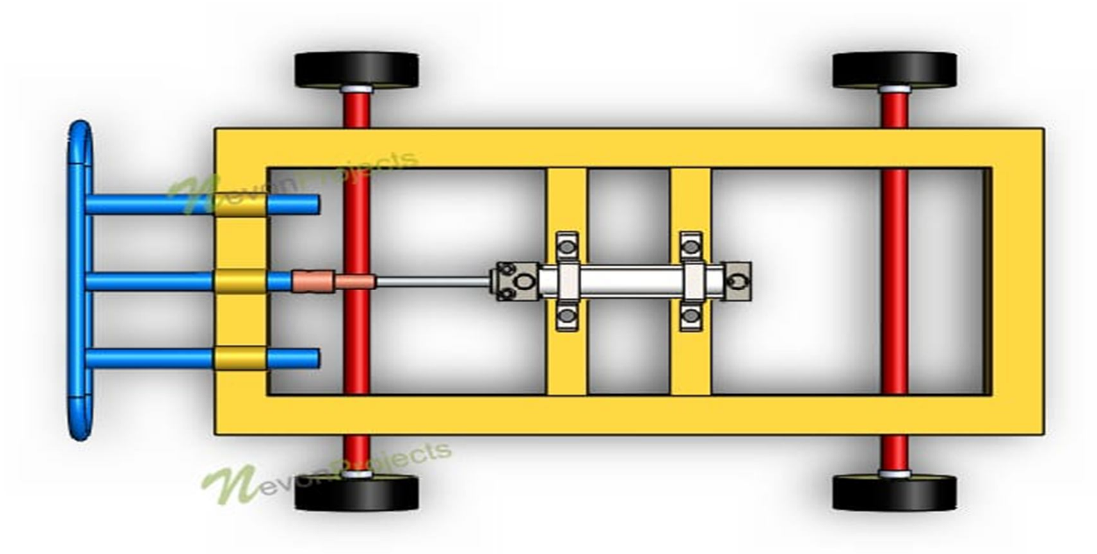
I. Impact Reduction and Safety

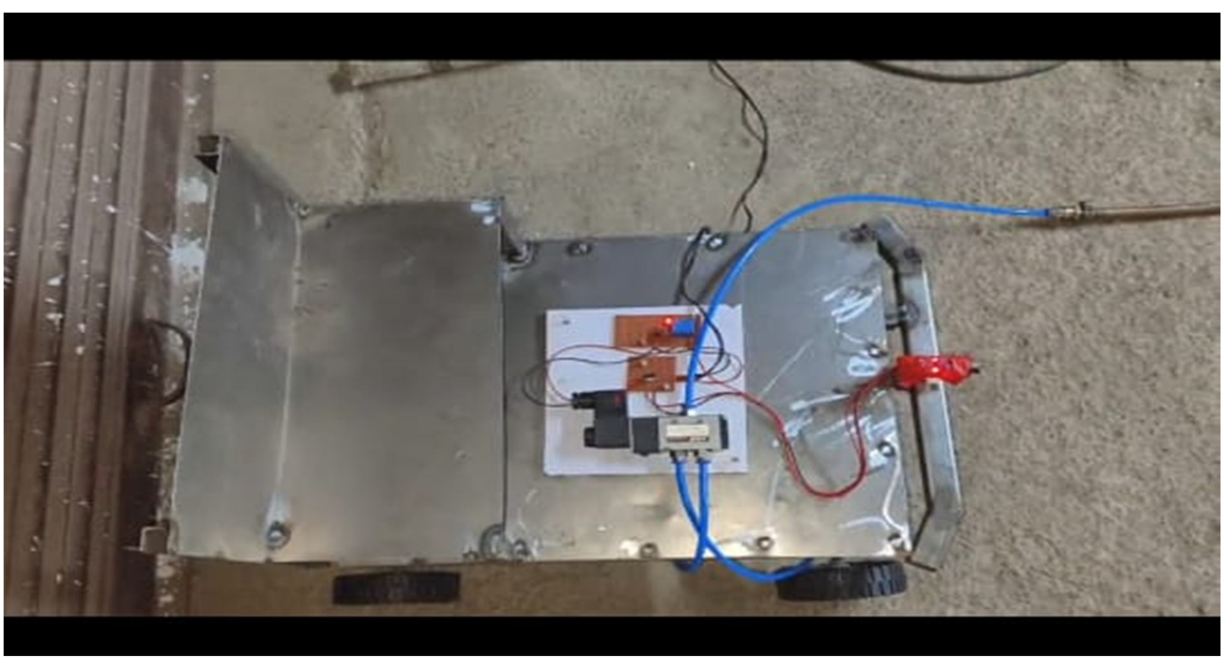
If a collision still occurs, the extended pneumatic bumper acts as a shock absorber. It reduces the impact force between the vehicle and the obstacle. As a result, the damage to the vehicle and the risk of injury to passengers are minimized.

J. System Reset

After the obstacle is cleared or the vehicle stops, the system can be reset. The compressed air is released, and the pneumatic cylinder returns to its original position, bringing the bumper back to its normal state.

3D View





III. LITERATURE SURVEY

A literature survey is an important section of a project report that reviews previous research related to the topic. Several researchers have studied automatic braking systems, pneumatic bumper mechanisms, and collision-avoidance technologies to improve vehicle safety.

A. *Automatic Braking System with Pneumatic Bumper Using Proximity Sensors*

Researchers Nilesh D. Patil et al. (2018) proposed an automatic braking system integrated with a pneumatic bumper using proximity or IR sensors. In their system, the sensor detects an obstacle in front of the vehicle and sends a signal to the control unit. The control system then activates the braking mechanism and the pneumatic bumper simultaneously to reduce the impact during a collision. The system improves braking response time and helps maintain a safe distance between vehicles.

B. *Automatic Pneumatic Bumper Car System*

A study by Abhinav Chaudhary et al. (2020) introduced an intelligent pneumatic bumper activation system combined with automatic braking. The design uses sensors to detect obstacles within a short distance (around 3–4 feet). When the obstacle is detected, a control signal activates both the braking system and the pneumatic bumper to reduce collision damage. This research highlights the importance of pneumatics in automation and automotive safety systems.

C. *Electro-Pneumatic Braking System*

Research by Ketan H. Mhatre (2018) focused on electro-pneumatic braking systems that apply brakes automatically when sensors detect obstacles in front of the vehicle. The system uses components such as IR sensors, pneumatic cylinders, compressors, and solenoid valves. The study showed that electro-pneumatic braking can stop vehicles quickly and reduce accidents caused by delayed driver reactions.

D. *Intelligent Bumper Actuation with Braking System*

Another research project developed an intelligent bumper actuation system with braking to minimize accident damage. The system automatically activates a pneumatic bumper and braking system when an obstacle is detected. This technology focuses on reducing collision impact and improving passenger safety in modern vehicles.

E. *Sensor-Based Braking with Pneumatic Bumper*

A study on an Eye Sensor Braking System with Pneumatic Bumper explored using electronic sensors and pneumatic technology to automatically control braking and bumper activation. The research highlights that pneumatic systems are widely used in industrial automation and can be effectively integrated into vehicle safety systems.

F. *Summary of Literature Review*

From the above studies, it is clear that integrating sensor-based obstacle detection, automatic braking, and pneumatic bumper mechanisms can significantly reduce the severity of vehicle collisions. Most research focuses on improving braking response time, reducing impact force, and enhancing passenger safety. These previous works provide the foundation for developing the Smart Braking System Using Pneumatic Bumper, which aims to further improve vehicle safety through automation and pneumatic technology.

IV. RESULTS AND DISCUSSIONS

A. *Simulation*

As we were instructed to solely focus on the functionality of blade, it was the only part we focused for simulation. 3D modeling of blade was imported to ANSYS. The analysis considered only static stresses and strain. No vibration or dynamic analysis was considered

Following process were carried out for simulation of Pneumatic bumper:

1) *Meshing:* Meshing is one of the fundamental parts of any engineering simulation process where complex geometries are divided into simple elements which can be used as local approximations of the larger domain. The mesh influences the accuracy, convergence, and the speed of the simulations.

For our simulation automatic meshing was conducted with a body sizing of 2mm. Figure 1 illustrates the blade after meshing.

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V. BOUNDARY CONDITIONS

In a Smart Braking System with Pneumatic Bumper, boundary conditions are the specific constraints and operating limits used to define the system's behavior during electronic control, mechanical actuation, and structural crash simulation.

1) Operational & Control Boundary Conditions

These define the "trigger" logic for the microcontroller (e.g., Arduino) to initiate the safety sequence.
* Detection Range (Distance Boundary):
* Caution Phase: Typically triggered when an obstacle is within 3–4 feet (approx. 1–1.2 meters).
* Emergency Phase: Automatic braking and bumper ejection often activate at a critical distance of 1–1.2 feet (approx. 30 cm).
* Speed Threshold: The system is often programmed to activate only if the vehicle exceeds a predetermined speed, such as 30–50 km/h.
* Reaction Time: The system must complete detection and actuation within a total time boundary—frequently cited as 1 second for full vehicle stoppage. [1, 2, 3, 4]

2) Mechanical & Pneumatic Boundary Conditions

These specify the physical forces and pressures required for the pneumatic cylinders to function correctly.
* Operating Pressure: Systems typically require compressed air at 4 to 7 bar (0.4–0.7 N/mm^2) to provide sufficient force for bumper extension and braking.
* Actuation Force: For a standard prototype, the assumed maximum force acting on the bumper is often calculated around 90N to 150N, with a Factor of Safety (FoS) of 1.25.
* Cylinder Constraints:
* Bore Diameter: Standard bore diameters used in research models are often 20 mm.
Stroke Length: The retractable bumper typically has a stroke length of around 120 mm. [5, 6, 7]

3) Finite Element Analysis (FEA) Boundary Conditions

When simulating a crash in software like ANSYS or SolidWorks, the following constraints are applied to the 3D model: [8]
* Fixed Constraints: The rear ends of the bumper assembly or the vehicle's chassis frame are usually set as fixed supports (zero Degrees of Freedom) to represent the rigid body of the car.
* Loading: An impact force (e.g., 1000N for simulation robustness) is applied directly to the frontal area of the bumper.
* Velocity: The impactor or the vehicle itself is assigned an initial velocity (e.g., 4 km/h for low-speed standards or up to 55 km/h for crashworthiness tests).
* Contact Conditions: "Slave" surfaces are defined for the bumper and "Master" surfaces for the rigid wall or obstacle to prevent mesh penetration during impact. [5, 9, 10, 11, 12, 13]

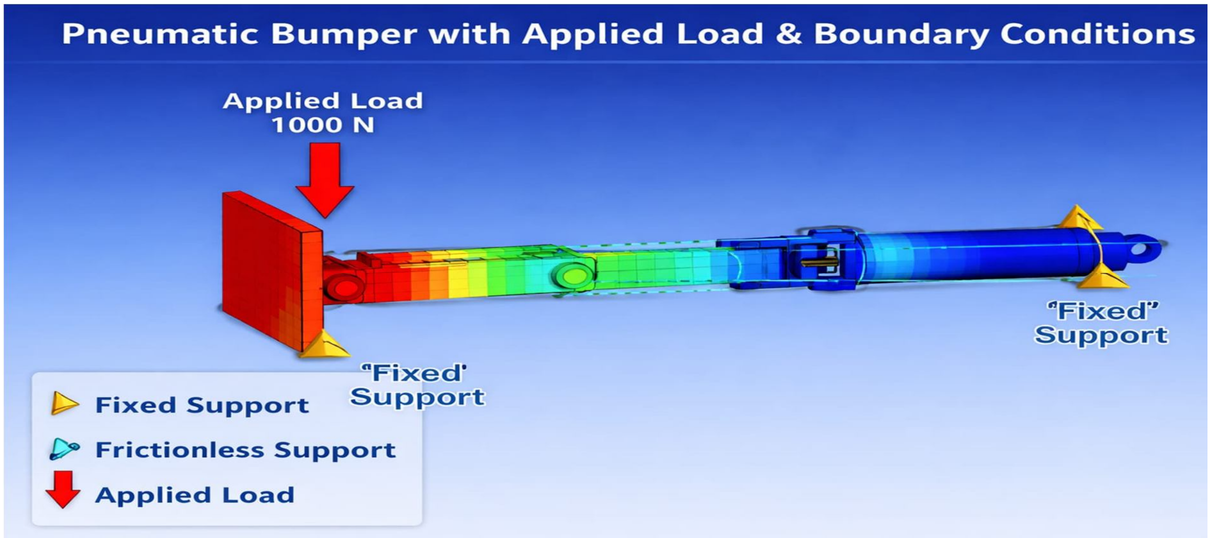

Figure 1 Shredder blade with applied loads and boundary conditions

A. Post Processing and Solution

Post processing is an important stage in engineering analysis where the results obtained from simulation or experimental testing are interpreted and evaluated. In the Smart Braking System Using Pneumatic Bumper, post processing is mainly carried out using Finite Element Analysis (FEA) tools to evaluate parameters such as stress, strain, and deformation in the pneumatic bumper structure when a load is applied

1) Finite Element Analysis (FEA) Post Processing

After completing the simulation of the pneumatic bumper model, the results are analyzed through post processing. The model is subjected to an applied load of 1000 N on the bumper surface while the other end of the system is kept as a fixed support. This helps to evaluate how the bumper behaves under impact conditions.

The simulation provides graphical outputs such as:

Total Equivalent Strain

Von-Mises Stress Distribution

Total Deformation

Boundary Conditions with Applied Load

These results help in understanding the mechanical performance of the pneumatic bumper.

2) Total Equivalent Strain Analysis

The total equivalent strain represents the amount of deformation experienced by the material due to the applied load

From the simulation results:

Maximum strain occurs near the bumper plate and joint region where the load is applied.

The strain gradually decreases along the connecting arm and pneumatic cylinder.

The cylinder region experiences minimum strain because it is supported and has higher structural rigidity.

This indicates that the bumper plate absorbs most of the deformation during collision.

3) Von-Mises Stress Analysis

The Von-Mises stress is used to determine whether the material will yield under the applied load.

From the analysis

Maximum stress occurs near the impact plate and hinge region

The stress value gradually reduces toward the pneumatic cylinder side

The maximum stress value is within the allowable limit of the material used for the bumper.

This confirms that the structure can withstand the applied load without failure

4) Deformation Analysis

Deformation analysis shows how much the pneumatic bumper structure bends or moves under the applied force.

From the simulation:

Maximum deformation occurs at the front bumper plate.

The deformation gradually decreases toward the cylinder and mounting support.

The deformation is within acceptable limits, ensuring that the bumper can absorb impact without permanent damage.

5) Boundary Conditions and Applied Load

For accurate simulation, proper boundary conditions are applied:

Applied Load: 1000 N acting on the bumper plate

Fixed Support: Applied at the mounting point of the pneumatic cylinder

Frictionless Support: Used at certain joints to allow smooth movement

These conditions replicate the real-life working situation of the pneumatic bumper system.

6) Solution and Interpretation

Based on the simulation and post processing results:

The pneumatic bumper successfully absorbs impact energy.

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Stress and deformation are within safe design limits.
The design ensures structural stability and safety during collision conditions.
The bumper mechanism effectively reduces the impact force transmitted to the vehicle body
Therefore, the Smart Braking System Using Pneumatic Bumper can significantlyimprove vehicle safety by reducing accident damage and protecting passengers.

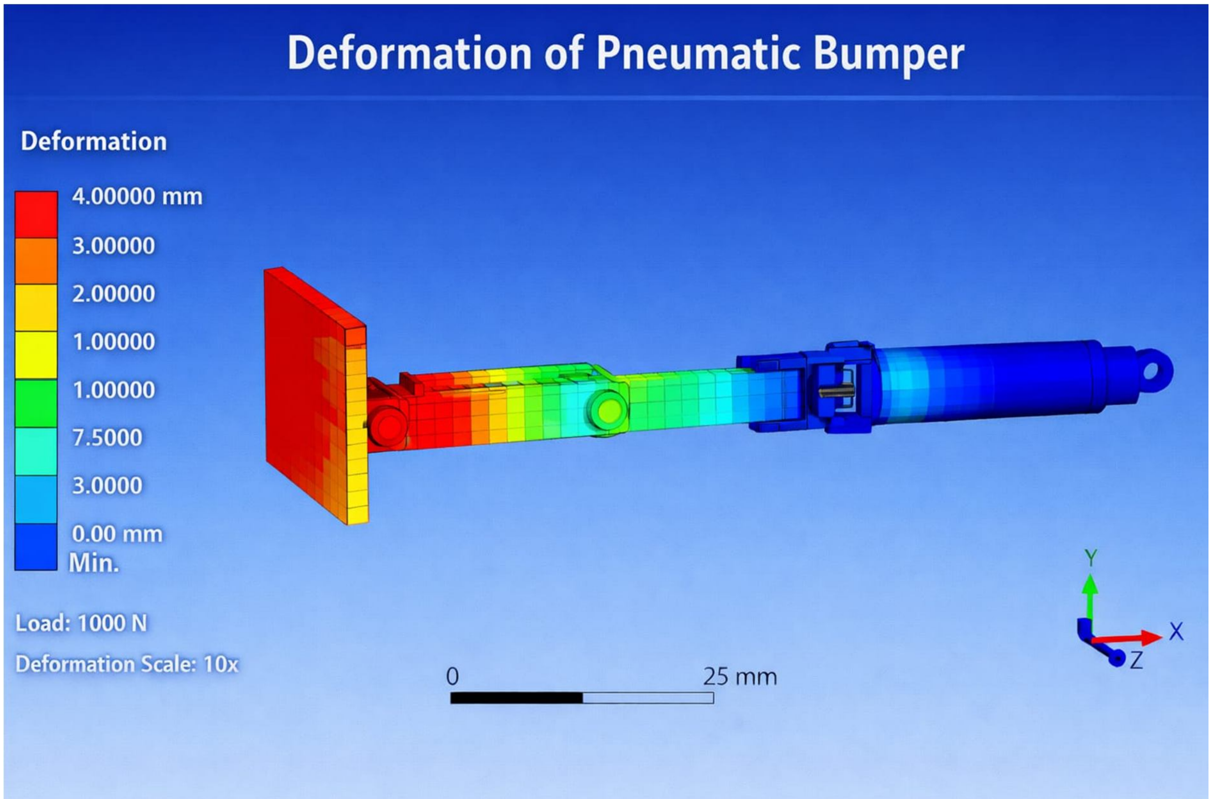

Figure 2 Deformation of blade

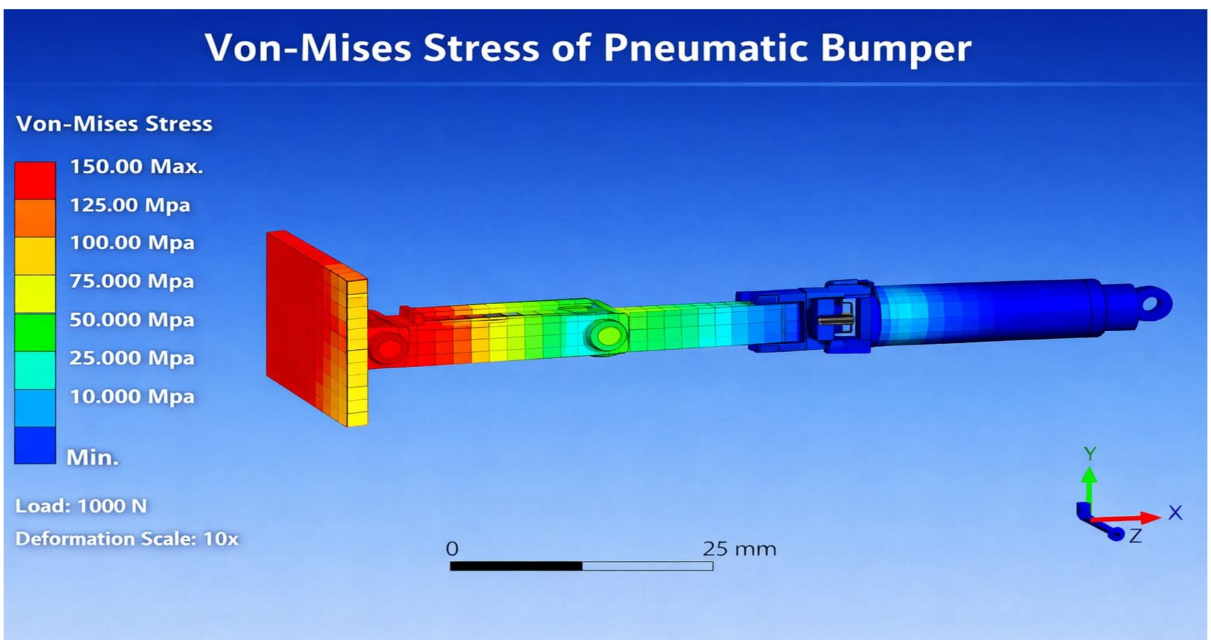

Figure 3 Von-Mises Stress

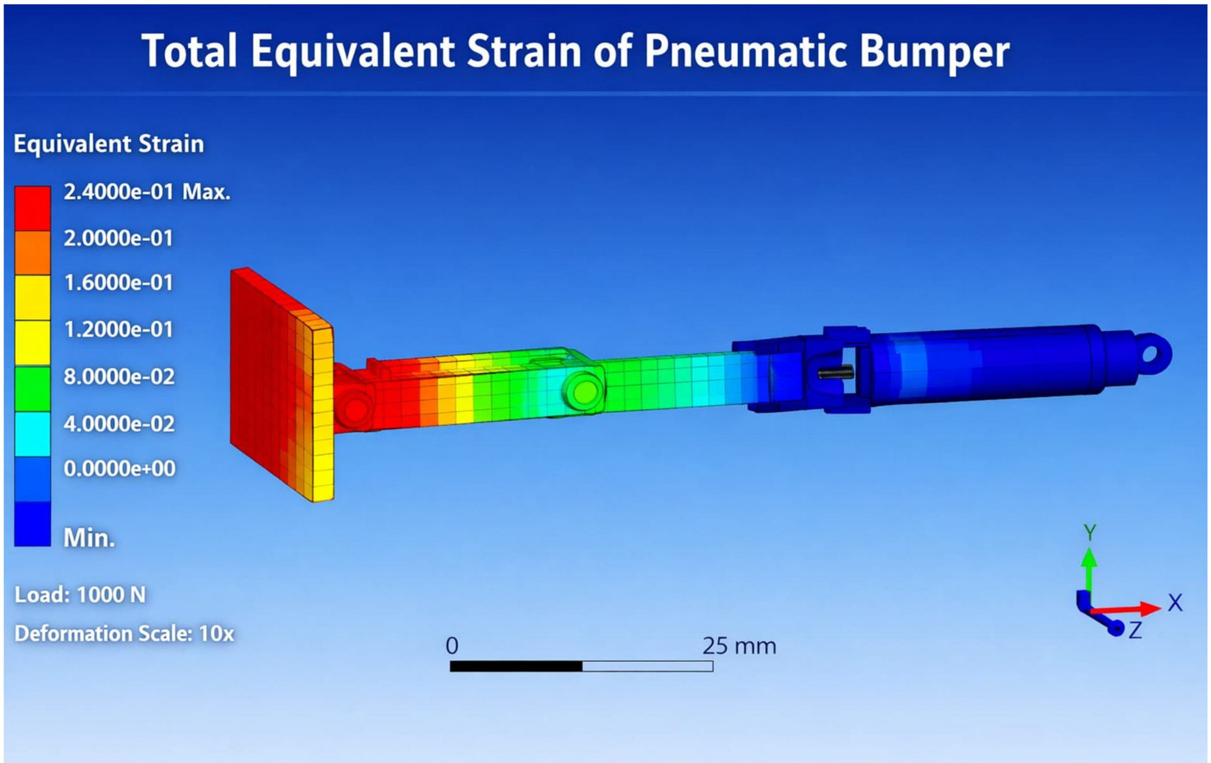

Figure 4 Total Equivalent Strain

VI. WORKING

The smart braking system with a pneumatic bumper is designed to improve vehicle safety by automatically detecting obstacles and reducing the impact of collisions. The system works with the help of sensors, a control unit, and a pneumatic mechanism. Sensors such as ultrasonic or infrared sensors are mounted at the front of the vehicle to continuously monitor the distance between the vehicle and any obstacle. When the vehicle approaches an object within a critical distance, the sensor sends a signal to the control unit or microcontroller. The control unit processes this signal and determines whether the vehicle is in danger of a collision. If the driver does not react in time, the system automatically activates the braking mechanism to slow down or stop the vehicle.

At the same time, the pneumatic system is activated through a solenoid valve that allows compressed air from an air tank or compressor to flow into a pneumatic cylinder. This pneumatic cylinder pushes the bumper forward, extending it from the front of the vehicle. The extended pneumatic bumper acts as a protective barrier and increases the distance between the vehicle body and the obstacle. If a collision occurs, the pneumatic bumper absorbs a portion of the impact energy due to the cushioning effect of compressed air inside the cylinder. This reduces damage to the vehicle and improves passenger safety. After the vehicle stops, the air pressure is released and the bumper returns to its original position, making the system ready for the next operation behind the plastic shredder is to reduce the volume acquired by the plastic waste during loading it to the recycling process.

VII. CONCLUSION

The smart braking system with a pneumatic bumper is an effective vehicle safety technology designed to reduce accidents and minimize damage during collisions. This system combines automatic obstacle detection, braking control, and a pneumatic impact-absorbing mechanism to enhance overall road safety. By using sensors to detect obstacles and activating automatic braking when necessary, the system helps prevent accidents caused by delayed driver reaction. In addition, the pneumatic bumper extends outward during emergency situations and acts as a shock-absorbing barrier, reducing the force of impact if a collision occurs. The compressed air in the pneumatic cylinder helps absorb energy and protect both the vehicle structure and passengers from severe damage. Therefore, the smart braking system with pneumatic bumper is a cost-effective, reliable, and efficient safety solution that can be implemented in modern vehicles to improve accident prevention and passenger protection. With further development and integration with advanced sensing technologies, this system has the potential to play an important role in future intelligent transportation systems.

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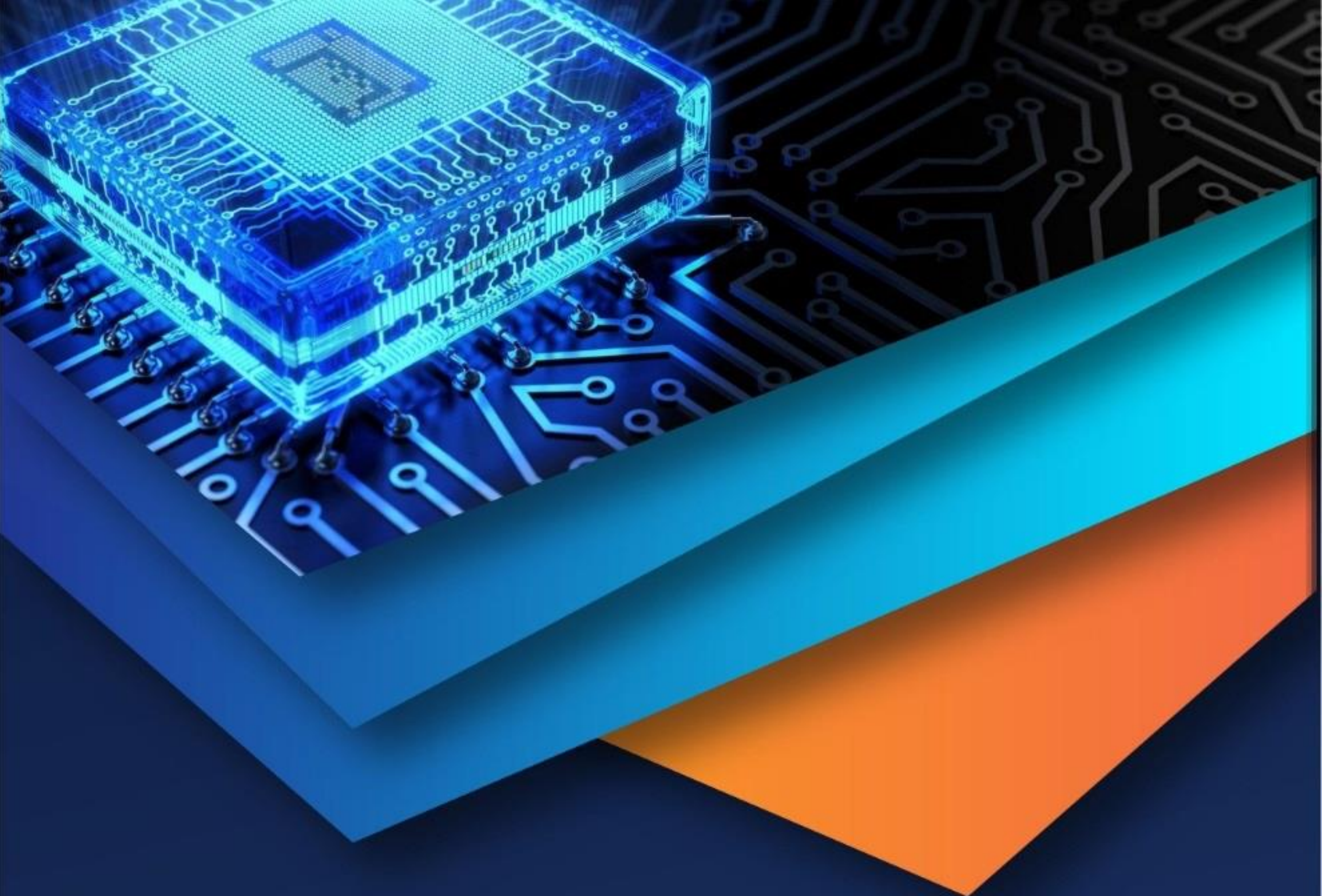

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