Proceedings of the 5th International Conference on Industrial & Mechanical Engineering and Operations Management, Dhaka, Bangladesh, December 26-28, 2022

Design of a QuickActing Braking System for Vehicle Safety Enhancement

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Abstract

Bangladesh's roadways are dangerous and have a high rate of fatal accidents. And one of the main causes of these mishaps is human mistakes. The magnitude of the issue is huge. It would be beneficial to upgrade the current cars with automatic accident prevention systems and vehicle safety features. Illustration of the circuitry, computer-aided design, design simulation, and power usage are only a few of the steps in the process. However, the maximum applied force on the brake is about 1424 Newton. Depending on the circumstance, the QABS (QuickActing Braking System) can override manual braking and apply a soft or hard brake. The QABS uses the automobile battery as its power source, and its critical braking power consumption is as low as 90 Watts. It was primarily created for vehicles of an older vintage that don't fall under the autonomous category. This braking aid can benefit drivers in decision-making and alert them to potential danger. The goal of this study is to create a dependable, responsive, and emergency braking system. It assists drivers who are intoxicated, distracted, or temporarily disabled, which promises to lessen the likelihood of accidents.

Keywords
Obstacle Detection, Collision, Quick-Acting Braking System, Safe Distance and Human Error.

1. Introduction
Government estimates indicate that more than 3,000 traffic accidents occur in Bangladesh each year, killing over 2,700 people and injuring about 2,400. This country has a high rate of fatal road accidents. These occurrences are expected to cause Tk 40,000 crore in yearly economic loss, or 2% to 3% of Bangladesh's GDP. The true death rate is most certainly much higher.

One of the major causes of traffic accidents is human mistakes. Drivers are prone to errors because of long driving shifts, road congestion, being intoxicated, etc. Designing an automated braking system can assist drivers in minimizing mistakes, fatalities, and property damage.

A thorough evaluation of relevant literature is the first step in the process of creating the quick-acting braking system. Based on the shortcomings of its predecessors, the QABS's features were chosen. The entire system was first imagined, and only then were the necessary components chosen. After that, a computer-aided design that could operate in sync with the circuitry was created.Additional components of the automation process were stitched together in the design process. Then, the components were simulated to find and fix faults. The discussion concluded with a brief comparison of static analysis and also power consumption for various brake settings.

2. Literature Review
The concept of an autonomous braking system is the subject of several articles. These systems develop autonomous brakes to lower the accident rate. An expert in this subject had recommended adding a collision detection unit as a general strategy for enhancing the brakes' use and potency. An ultrasonic sensor was used in research to achieve this

feat, and an LCD and a blinking LED are used to notify stops. To achieve the best braking force and shortest braking distance, a servo motor had been connected to the parking brake lever. The Arduino Mega 2560 microcontroller, which was created specifically to carry out the task at hand, was used to manage these devices (Chirantana and Kanth 2015). A servo motor was proposed to be replaced with an electric pump and solenoid valves in another article from 2019 while other parts were the same. The ultrasonic sensor in the setup can measure the distance between objects and the car being driven. The brake system is controlled by solenoid valves and a hydraulic pump. This mechanism might cause the car to stop without the driver's input if the driver didn't apply the brakes at the appropriate moment. The device performed flawlessly, and the differences between the measured and theoretical braking times ranged from 1% to 2% (Allam et al. 2019). Another study used sensors to keep track of the driver's surroundings and inform them of various ambient conditions. They developed an automatic speed control system and used sensors to prevent accidents. To prevent a collision, the cars' distance from one another is maintained using an ultrasonic sensor. It alerts the driver when the car horn sounds by vibrating the driver's gloves (Brindha et al. 2020). Using IR sensors and relays, a workable solution for autonomous braking system regulation to prevent accidents was proposed. The entire braking control system should be positioned on a car's dashboard in order for it to perform its valuable role. The parameters were used to automatically control the brakes (Soule et al. 2020). Combining this IR system with other subsystems like automatic traction control, intelligent throttle control, and the auto cruise control can further improve it. If true, a startling and deft vehicle maneuver would ensue (Koli et al. 2017). Another research proposed an autonomous microcontroller-based accident avoidance system that makes use of obstacle detection and distance measurement using ultrasonic sensors to identify barriers and their locations. However, a speculative combination of ultrasonic and radar-based sensors might result in a more successful automotive safety system (Aliyu et al 2017). In order to promote pedestrian safety, a study proposed to combine the capabilities of Vehicle to Vehicle and Pedestrian Automatic Emergency Braking System (V2V-PAEB) (Tang et al. 2016). This will allow pedestrian information detected by onboard sensors of a vehicle to be sent to the V2V network. Another work presented the concept of an ABS based on fuzzy logic and implements it in hardware by using a remote-controlled car. The inputs to fuzzy logic are the speed and distance of the object in front of the car, and the output is the amount of braking (Basjaruddin et al. 2016). An alternative approach makes use of an image processing unit (IPU) to recognize pedestrians in particular image regions. When it comes to actual use, this system is really practical. However, they were only available to actual pedestrians, pretend pedestrians, and non-pedestrians. The technology is not capable of detecting obstacles (Ariyanto et al. 2018). When faced with solid obstructions, the ultrasonic sensor operates squarely, but the outcome does not support scattered items. For greater performance and stability, the AEB system might have been used with either a LIDAR in place of an ultrasonic sensor or numerous ultrasonic sensors. If a solenoid had been employed, the AEB unit's design could have been simpler (Broggi et al. 2009).

One study described an integrated dynamics and control modeling process for a four-wheel vehicle's braking system. The system of the vehicle consists of various energy zones. Models in many energy domains and control systems are integrated using the multidisciplinary modeling approach known as the bond graph. To assess the effectiveness of the ABS system under various operating conditions, the bond-graph model of the integrated vehicle dynamic system is constructed in a modular and hierarchical modeling environment (Bera et al.2011). Another researcher presenteda full-size prototype of a regenerative braking system. To validate their claim, simulations and experiments were carried out. According to the recorded data, the braking energy recovery system can achieve an auxiliary starting torque of 12.7 N-m, amaximum voltage of 3.5 V, and total energy recovery efficiency of 0.53, proving its efficacy and value for vehicle energy savings (Qiet al. 2020). The brake disk's deformations, the corresponding Von Mises stresses, and the distribution of contact pressure on the brake pads were noted in a research work. Numerous inferences can be made in light of the investigation's findings. They were able to deliver a top-notch rotor design to ensure the vehicles' improved braking performance (Belhocine and Abdullah 2022). A CAD model was madeto help the readers understand the hybrid design. Analytical modeling of the recovered energy was done after that. According to the investigation, the angular velocity significantly affected both energy efficiency and power loss. The outcomes demonstrated that the hybrid one can offer more efficiency, however only when functioning within specific constraints (Wen and Tien 2018).

The studies above discussed using infrared, ultrasonic, or image processors to find various obstacles or incoming obstacles. None advocated the application of several sensors. In every instance, the sensor is normally installed on the front of the vehicle; however, the back has never been taken into consideration. We acknowledge that certain cars have a rear camera. But rarely, these are utilized to see the background. A harsh brake is applied by an automated mechanism. This unexpected halt might not be the best way to handle problems. So it is preferred to brake the car gradually. Recent works ina similar field emphasize regenerative braking systems and occasionally focus on hybrid braking systems. But the use highlights a relatively newer generation of cars.

3. Methodology

The structure of the methodology must include numerous sequential and organized steps. Identifying the brake's parameters, particular functions, and operational mechanisms is the first stage. The background data and important decision-making criteria are gathered in this step. In the following step, the electrical configuration is needed to be determined using component analysis and circuit diagrams. The mechanical brake components must then be designed such that they precisely fit into the current system and resonate with the electrical circuit. The simulation of actual force and torque will be used to improve the designs of mechanical components. The designed components are then assembled and rendered. The final stage should validate the model in terms of its cost, complexity, power usage, etc.

3.1 Parameters

A designer must take into account different factors employed in the input, process, and output phases when creating a system. Similarly, various internal and external factors were taken into account for this braking aid.

Velocity: The vehicle's speed is an important consideration. The Arduino program was developed based on the assumption that the velocity was 80 km/h. For any vehicle arriving from the side, the maximum relative velocity was 80 km/h, while for vehicles coming from the rear, it was 30 km/h.

Distance: According to our research on vehicle speed, two cars coming from different directions at an average speed of 80 km/h must brake at a minimum distance of 60 m, as illustrated in Figure3. This safe distance was calculated under the conditions of an 80% effective braking system, a wet road, and a prompt driver response.

Frequency: The brake system has an internal buzzer that sounds periodically to warn the driver. To convey various scenarios to the driver, various frequencies were employed. Instead of continuously expanding or diminishing patterns, square waves are used (Figure 1). The range of frequencies used for this project is from 100 Hz to 500 Hz.

Figure 1. Square wave

Sound: Sonar sensors were utilized to measure distance (Figure 2). It is safe to use this sensor because it makes a sound that humans cannot hear. To prevent one sensor from being impacted by the other, we must put two sensors facing different directions.

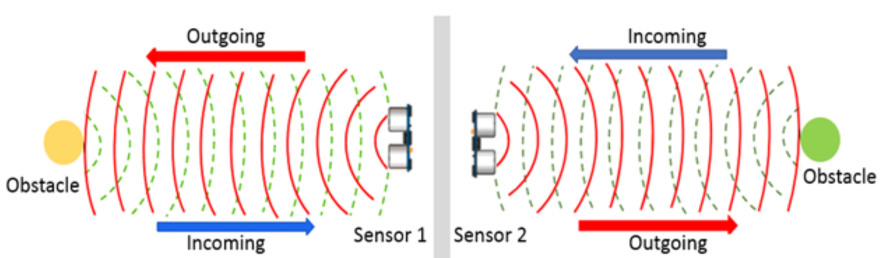

Figure 2. Orientation of the sensors

Time: Sound travels at a velocity of 340 m/s. A car will be detected by the sensor in about 352 milliseconds if it is within 60 meters, which is much quicker than human drivers. Figure3 depicts the recommended separation.

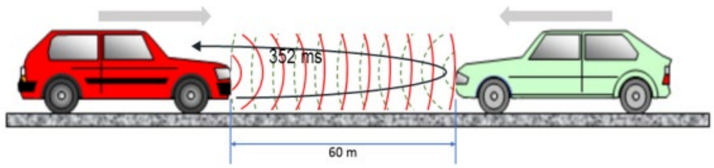

Figure 3. Safe distance &time required

3.2 Function and Block Diagram

The main job of the braking system is to analyze the situation as it happens, alert the drivers to their surroundings, and apply the brake. Figure 4 depicts the project.

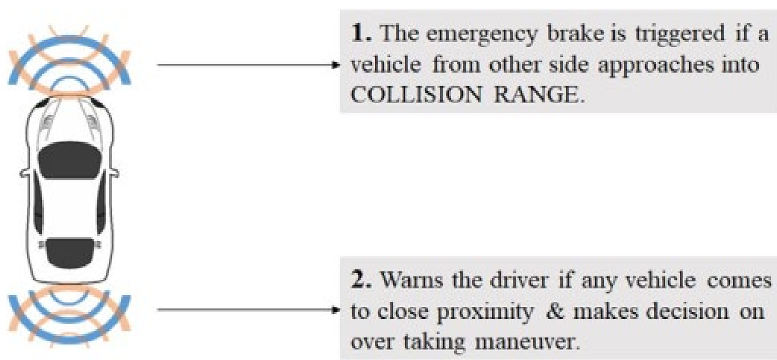

Figure 4. Functions of the braking system

The display unit, indication LED, and buzzer are some of the communication channels the system has available for use with the driver. Figure 5 depicts how various components operate under various circumstances.

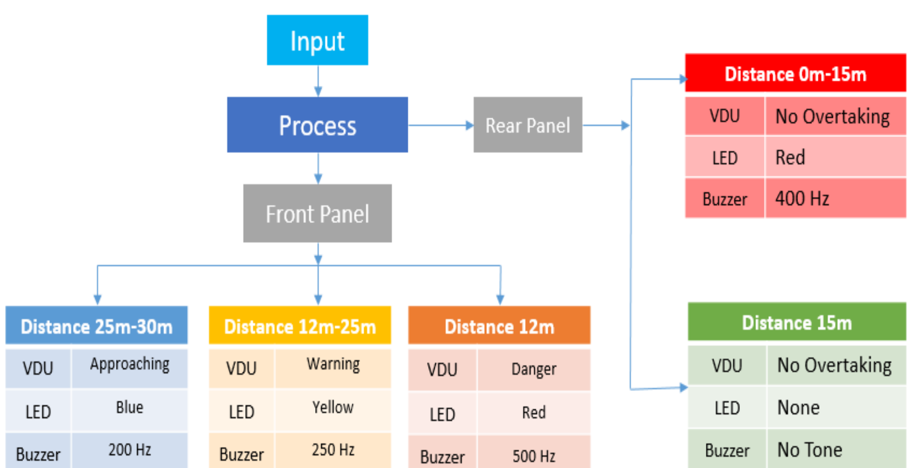

Figure 5. Block diagram

3.3 Working Logic

Ultrasonic waves are transmitted by proximity sensors at the front to detect any close objects. Arduino calculates the object's distance by dividing the time between transmission and reception. The buzzer, indicator, or screen does not display any activity at separations longer than 30 meters. The LED indicator lights up and the buzzer begins to ring if the distance is between 25 and 30 meters. The buzzer buzzes louder, flashes a warning message, and uses a transducer to slowly start the brake when the distance drops to the range of 12 to 25 meters. If the gap narrows much more, an immediate hard brake is applied to prevent a collision.

When attempting an overtaking move, the use of rear proximity sensors alerts the driver to vehicles that are nearby (less than 15 m).

3.4 Electrical Component

The components used in this study are listed below-
1) Arduino, 2) Buzzer, 3) Ultrasonic Sensor, 4) LED Light, 5) Resistor, 6) LCD Display, 7) Battery, 8) Electro-magnet

3.5 Circuit Diagram

The circuit diagram of the braking system is shown in Figure 6.

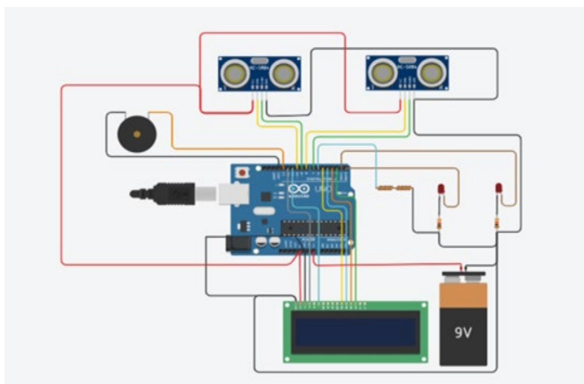

Figure 6. Circuit for QABS

3.6 Mechanical Design Components

The braking system has several mechanical and electrical parts. The mechanical construction itself is very simple. Here the automation components are projected over the conventional braking mechanism. The automation process effectively affects the pedal, connector, and solenoid shaft. So, the load-bearing capability of these components must match their non-automated counterpart. Figure 7 illustrates the various mechanical components of the system.

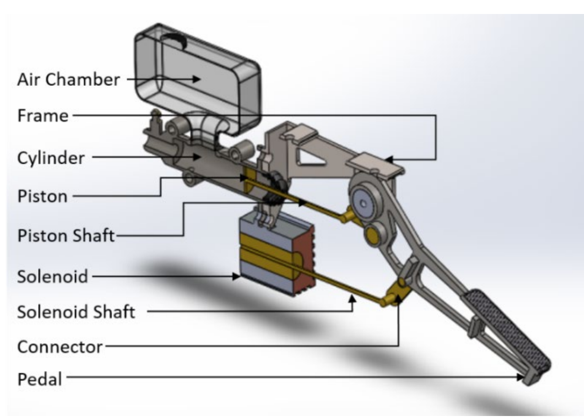

Figure 7.Mechanical components of the QABS

3.7 Force and Toque Analysis

It was identified that, while driving, drivers exerts about 200 Newton on the pedal. But this force can be as high as 600 Newton in case of the failure of the vacuum booster (Quora, 2017).So, a 600 N force is supposed to be applied at C which results in M_A moment at A as illustrated in Figure 8.

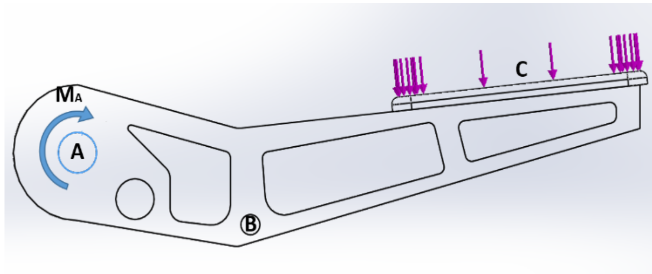

Figure 8. Direction of force and torque on the pedal

Moment about A, M_A

$= F_A*D_{AC}$

= (600*0.1778) Newton-meter

=106.70 N-m

To activate the automatic brake the applied maximum torque must be 106.70 Newton-meter. But in this case, the force would be applied at B rather than at C. So, the required force at B is-

$F_B = (M_A/D_{AB})$

= (106.70/0.07493)

= 1424 Newton

The pathway of transferring external force is summarized below-

Manual Brake: driver→C→piston→brake

Automatic Brake: solenoid→E→D1, D2→B→piston→brake

This means, 1424 N force (at most) would transfer from the solenoid to the shaft, from the shaft to the connector, and finally to the pedal. Where it will press the fluid against the cylinder to initiate the brake.All the associated members and their points of action at the members are depicted in Figure 9.

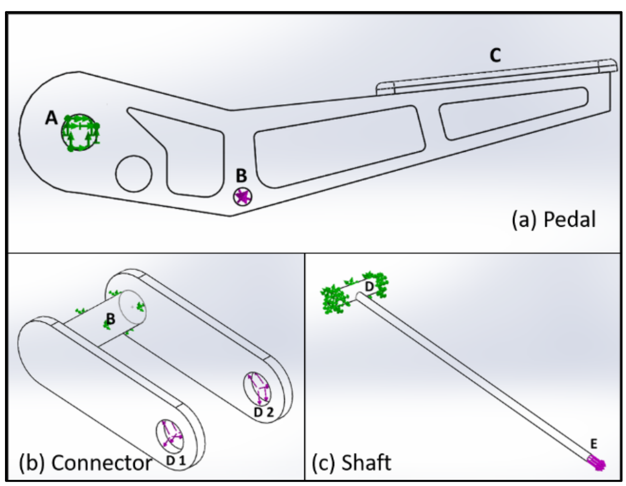

Figure 9. Position of geometric fixtures and external forces

3.8 Simulation

Components are made of different materials and contain certain geometric characteristics. So, their load-bearing capacity is not the same. To test the design functionality, the components are subjected to static analysis to simulate their behavior under influence of external force.The simulation was performed specifying 1424 Newton force acting at different locations of the components. The purple arrows specify the location of the applied external force while the green arrows indicatethe anchoring surface for the simulation as demonstrated in Figure 9. Underlying Table 1 is a summary of representing component characteristics during the simulation.

Table 1. Simulation parameters

Serial	Component	Material	Fixed Position	External Force	Yield Strength (N/m^2)
1	Pedal	Al-2004 alloy	A	B	9.6E+07
2	Connector	Brass	B	D	2.4E+08
3	Shaft	Ductile cast Iron	D	E	5.5E+08

3.9 3D Modeling

The 3D design shown in Figure 10 illustrates the physical overview of the braking system. Unlike a general setup, two connecting rods are aligned with the brake pedal. The first one serves a traditional function, pressuring the fluid inside the cylinder. The second rodis connected with a powerful short shaft pull-push type solenoid. When the central unit finds the urgency to initiate the brake without the driver's consent, the solenoid turns on and sucks the connecting rod inside, which creates a push-in effect for the brake pedal. So, the fluid gets compressed against the chamber, meaning the activation of the brake. The central unit determines the required braking force and instructs the solenoid accordingly.

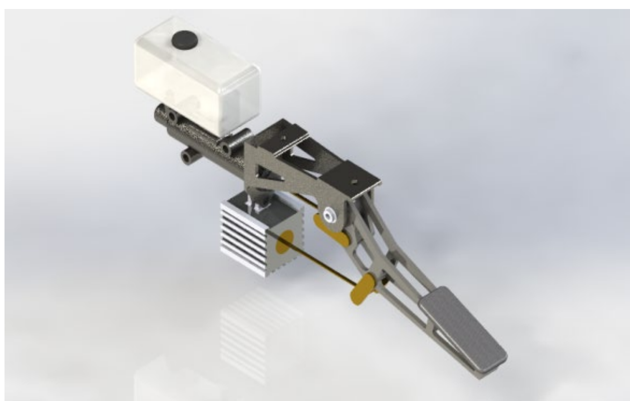

Figure10. Final assembly (Rendered)

3.10 Power Consumption

With longer strokes, the holding power decreases noticeably. Three distinct coils are housed simultaneously in the solenoid utilized in this project to represent various conditions. Therefore, the holding force that is generated would not change. According to Table 2, it is obvious that increased braking action causes the solenoid's stroke length and power consumption to increase. For the system to apply its maximum braking force, 90 watts are needed.

Table 2. Power consumption of various stroke lengths

Percentage of Brake Applied, %	Voltage, V	Stroke Length, inch	Current, Ah	Power, W	Holding Force, N
50	12	1-1/8	3.75	45	100-110
80	12	1-4/5	6.00	72	100-110
100	12	2-1/4	7.50	90	100-110

4. Results and Discussion

Simulating parts under loading conditions played a critical role in evaluating the design. The simulation process included stress analysis, Factor of Safety, displacement, and strain analysis. Outputs of the simulation for every responsible member are presented in Figures 11-13.The simulation showed that under loading conditions the structure performs excellently.

Stress analysis showed the stress is localized in the slot where the connector is attached. The displacementof the pedal is not significant enough as it is only 1.15E-03 mm. And the maximum strain is 1.1E-04.

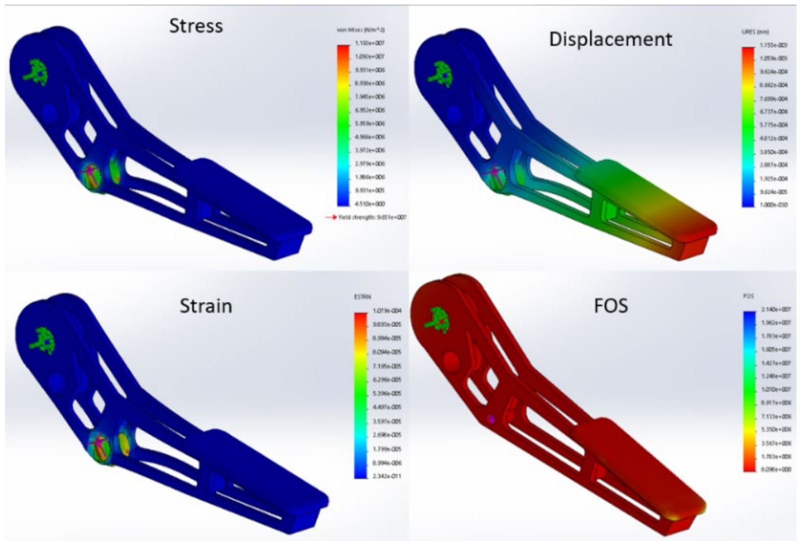

Figure 11. Static analysis spectrum of pedal

Similarly, the connector has shown the capacity of enduring local stress which is limited to 2.9E+07. Here displacement is slightly high (only 1.2 mm). The maximum recorded strain is 2.3E-06 with a minimum factor of safety to be 8. The factor of safety is considerably high but it is justified because this component may have to endure additional fatigue forces while in use or being installed.

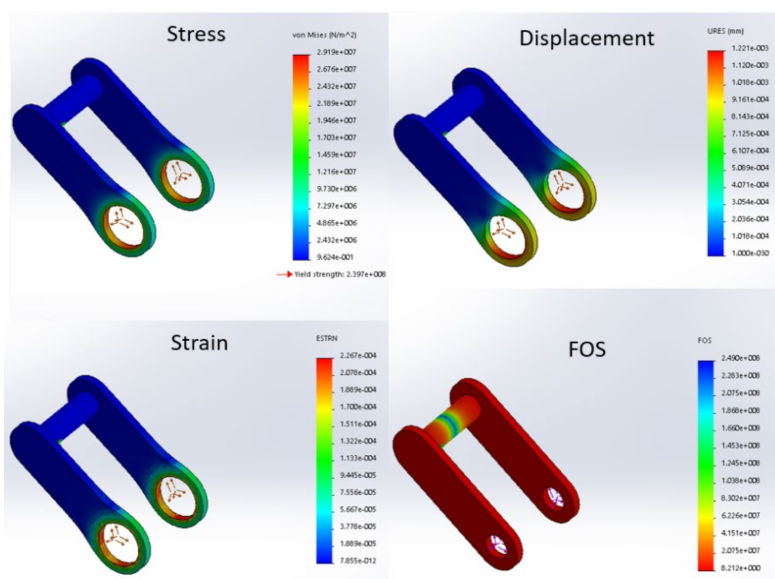

Figure 12. Static analysis spectrum of connector

The solenoid shaft is a critical component as it contains magnetic property to be pulled or repelled by the solenoid and functions as a secondary lever to actuate the brake. The static properties (stress, strain, and displacement) are considered for the operation. The minimum factor of safety is 3 which could have been raised to a higher value by design modification. But the modification is limited by the size of the solenoid.

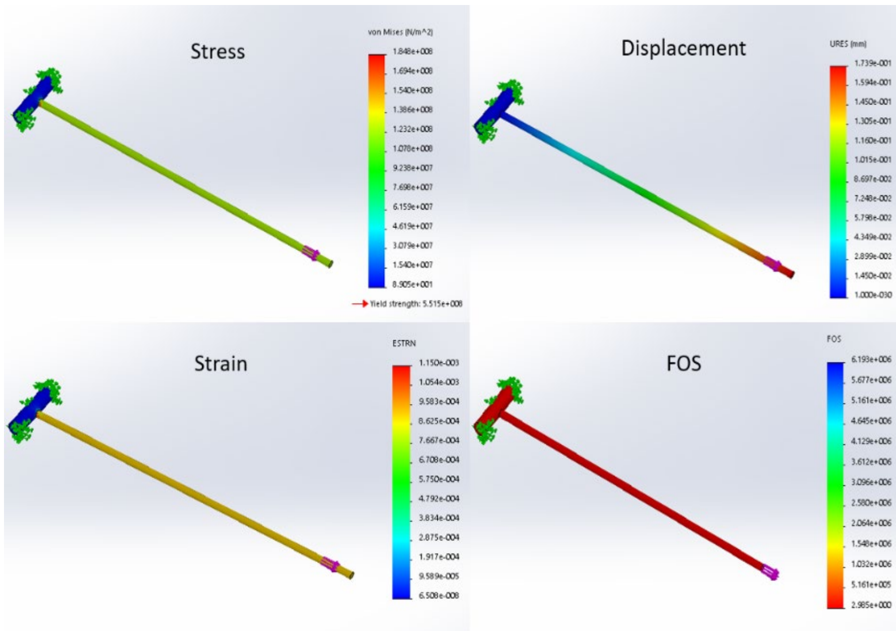

Figure 13. Static analysis spectrum of solenoid shaft

5. Conclusion

Numerous possible uses for the proposed braking mechanism exist, particularly in developing nations. Utilizing this technique in a four-wheeler can lower the accident rate. In this setup, the processor uses ultrasonic sensor data to calculate the separation between other cars on both the front and back sides, and if it detects an item within 50 to 60 meters, it sends an emergency alert via a buzzer and orienting alarm on the LCD panel. The electric transducer starts strong braking as needed when the object is25 meters away.The maximum external force employed on the brake is 1424 Newton transmitted from the solenoid to the pedal through the shaft and connector. Simulation of the Pedal, the Connector, and the Shaft illustrated stress, strain, and deformation are in considerable limit. A brief power computation has shown that the brake requires about 90 watts of power to run.The study promotes the bi-directional sensing of obstacles with sensors facing the front and rear of the concerned vehicle. The methodology contains electrical and mechanical configurations, simulation, and power consumption rather than focusing on a single issue. It does not suggest redesigning the brake but rather speaks about the ways of modifying the existing brake. Thus, creating opportunities for the older generation of brakes to thrive.

However, this project has room for improvement in the future.To measure distances more effectively, an image processing sensor or LIDAR technology can be used.A Vehicle to Vehicle (V2V) data transfer system can be implemented to increase the effectiveness of the braking system even more. Furthermore, the design of the components can be improved using tropology optimization but this process will also increase production costs.

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