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Integrated Approach to Enhance Vehicle Safety: A Novel Bumper Design with Energy-Absorbing Mechanisms

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Abstract

This research focuses on improving vehicle safety by developing a new spring-based energy absorption system for the front bumper of a Bolero vehicle. The goal is to reduce the severity of frontal collisions by absorbing a significant portion of the impact energy. The proposed system comprises a helical compression spring, a mounting bracket, and a chassis member. This design aims to absorb 30-35% of the energy impact, reducing the deceleration rate and minimizing the shock transmitted to the passenger cabin. To visualize the system and estimate its energy absorption capabilities, a 3D CAD model and analytical calculations have been performed. Further analysis using finite element methods will provide a more detailed understanding of the deformation behaviour of the bumper and spring, as well as the energy absorption capacity of the shock absorbing. Future work will involve refining the design, conducting detailed analysis, and evaluating the performance of the system through rigorous testing. This research has the potential to significantly enhance vehicle safety and mitigate the risks associated with frontal collisions.

***Major Findings:** A novel spring-based impact energy absorption system was proposed to reduce the severity of frontal collisions by 30-35 %. Finite element analysis was conducted to assess the system's deformation behaviour and energy absorption capacity. The four-damper system demonstrated a 42.44% reduction in maximum deformation compared to a plain bumper. The proposed system has the potential to significantly enhance vehicle safety.*

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Keywords: *Bumper, Crash Safety, Helical Compression Energy Absorption*

1.0 Introduction

People increasingly rely on private vehicles for travel, leading to a surge in road traffic. While accidents cannot be eliminated, efforts are made to reduce fatalities by improving occupant safety. Vehicle safety and energy absorption during crashes are crucial factors in automotive design. Severe accidents can result in fatalities, making energy absorption essential. Current safety systems, like airbags, are primarily available in high-end vehicles. However, the impact of energy generated during accidents can be mitigated through safety measures and devices. One solution involves using appropriately designed helical compression springs and dampers to absorb mechanical energy during impact. This safety system reduces collision energy by absorbing impact energy at the point of a frontal impact. NX software-based design of impact absorbing mechanism is shown in Figure 1 and heavy vehicle contributions in accidents are shown in Figure 2. The paper[1] proposes a microcontroller-based system to enhance vehicle safety by automatically applying partial braking to mitigate crash risks and by taking over acceleration control in critical overtaking scenarios. This research investigates the safety of a compact, tilting, electric vehicle designed for urban use, focusing on battery system integrity during potential crash scenarios[2].

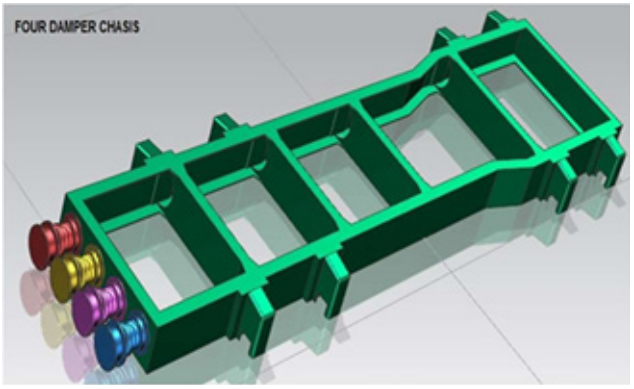


Figure 1. NX software-based design of impact absorbing mechanism[1].

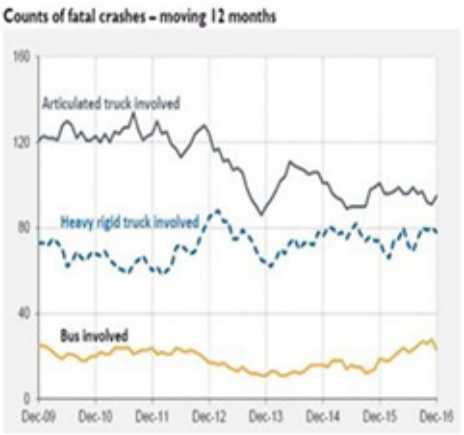


Figure 2. Heavy vehicle contributions in accidents[2].

2.0 Literature Review

Researchers have highlighted the energy-absorbing capabilities of composite materials, especially those reinforced with natural fibres like jute. Deshpande emphasized the human and financial costs of accidents. Despite various road safety initiatives, India witnessed a significant number of road accidents and fatalities in 2018[3,4]. The use of composite materials in automobiles to reduce weight and improve fuel efficiency. These materials can be used in various components like seating, bumpers, dashboards, and exterior parts. The automotive industry has seen a significant increase in the use of plastics, particularly composites, due to their high strength, stiffness, and energy-absorbing properties[5,6]. Researchers have further investigated the potential of nanocomposites and traditional composites for enhancing crashworthiness. These materials can be engineered to absorb energy effectively and provide controlled deformation during impacts[7]. Researchers discussed the trend of replacing conventional materials with composites in the automotive industry, leading to weight reduction, improved fuel efficiency, and reduced emissions[8]. Researchers highlighted the challenges faced by automotive manufacturers in meeting stringent design and performance requirements within shorter development cycles. CAE tools, such as CAD and FEM, have become essential in designing efficient and cost-effective solutions. The research also presented a novel bumper design that utilises a spring mechanism to absorb impact energy and reduce weight compared to traditional steel bumpers[9]. The study examines various

thermal management strategies and advancements in heat transfer technologies. It includes the impact of substrate thermal conductivity on electronic component temperature regulation, PCM cooling for smartphone circuits, CFD-based thermal management of IC chips, AI-driven IC chip placement for optimized cooling, and water-efficient hygienic faucets for public spaces[10-13]. The research also reviews and experimentally investigates heat transfer enhancement in tubular heat exchangers using methods such as jet impingement, twisted tape inserts, and nanofluids[14-22]. Key areas explored include optimizing aerofoil designs, predicting heat transfer improvement with twisted tape inserts, and assessing the influence of wavy corrugated twisted tape inserts and circular holes in double-pipe heat exchangers. Furthermore, it evaluates the thermal performance of electronic components on different substrate materials and the heat transfer behaviour of symmetric and asymmetric IC chips mounted on SMPS boards, both with and without the integration of Phase Change Materials (PCM)[23-34].

This research aims to design and analyze a novel spring-based impact energy absorption system for the front bumper of a Bolero vehicle, aiming to reduce the severity of frontal collisions by absorbing a significant portion of the impact energy and minimizing the shock transmitted to the passenger cabin.

3.0 Design of Front Bumper of Vehicle [LMV and HMV]

A bumper, a shield made of steel, aluminium, rubber, or plastic, is mounted on the front and rear of a passenger car. In low-speed collisions, typically up to 5-10 mph, the bumper system absorbs the shock to prevent or reduce damage to the car. Some bumpers use energy absorbers or brackets, while others use foam cushioning. Car bumpers are designed to prevent or reduce physical damage to the front and rear ends of passenger vehicles in low-speed collisions. However, they are not designed to be structural components that significantly contribute to vehicle crashworthiness or occupant protection during front or rear collisions. They are not safety features intended to prevent or mitigate injury severity to occupants. Instead, bumpers are designed to protect the hood, trunk, grille, fuel, exhaust, and cooling systems, as well as safety-related equipment such as parking lights, headlamps, and taillights in low-speed collisions.

4.0 Design of System

4.1 Material Selection

The bumper is the first part of the vehicle which will face maximum striking forces. To minimize the effect of collision, we must choose an effective material which will have good anti-collision properties. EPDM is the material which fulfils this requirement. EPDM material has the following chemical composition and mechanical properties as mentioned below in table 1. This table presents the mechanical properties of five different materials (A, B, C, D, and E). The properties include tensile strength, elongation, modulus at 100% elongation, hardness, and tear strength. These properties are crucial for understanding the material's behaviour under stress and strain. Figure 3 shows the chemical properties of EPDM material.

The following are the chemical properties of EPDM material which is essential while designing a bumper.

Table 1. Mechanical properties of EPDM material

Property	A	B	C	D	E
Tensile Strength (MPa)	7.8	13.6	16.5	22.7	20.2
Elongation (%)	393	555	581	636	584
Modulus at 100% (MPa)	1.2	1.3	1.4	1.9	1.8
Hardness (Shore A)	49	60	53	61	59
Tear Strength (KN/m)	20.9	27.1	30.3	39.6	39.5

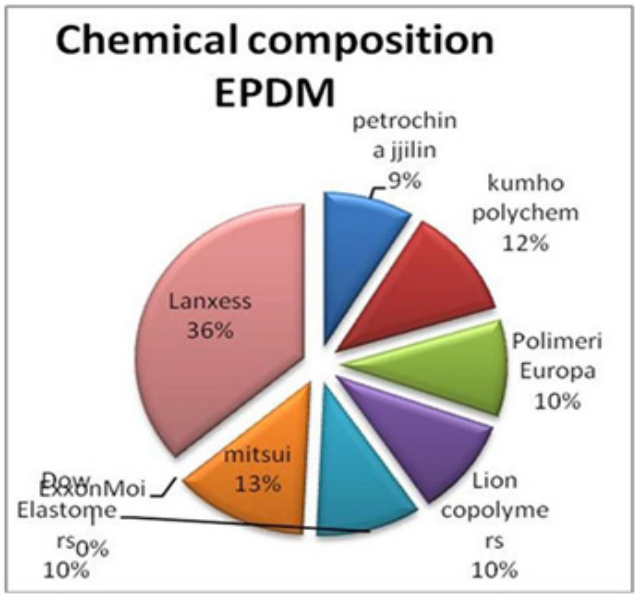


Figure 3. Chemical composition.

4.2 Calculation for Impact Force to be Considered

The proposed impact energy absorbing system design consists of two significant subsystems: first could be a helical compression spring, which can act as energy during a crash. Second is the mounting arrangement of springs with a damper mechanism. The preliminary task is to calculate the looking force on the system. Consider the front collision of a vehicle with a stationary wall. Number of energy generated thanks to collision is calculated by assuming the passenger vehicle as bolero has mass (m) 1620 kg. The impact distance is taken into account to be 5 m and the width is considered to be 1200 mm for spring placement with spacing between springs to be 300 mm Four springs are placed considering the equal spacing and equal distribution of impact load within the frontal cortex of bumperto soak up the energy generated during a crash with maximum velocity (v) of impact at 90 km/h or 25m/sec Impact force, consistent with mechanics, could be a shock or high force applied over a brief period when two or more bodies are into collision.

5.0 Calculations of Spring

5.1 Rates and Loads

Spring rate (spring constant), K = 1,031.787 N/mm

True maximum load, True Fmax =12,881.933 N
Maximum load considering Solid Height =0.000N
Safe Travel-
Potential true maximum travel wl longer free length, true travel max = 12.485mm Maximum

5.2 Physical Dimensions

Diameter of spring wire, d = 20 mm Outer diameter of spring,
D = 100mm Inner diameter of spring

Table 2. Parameters of spring

Mean diameter of spring D(mean)	=80mm
Free length of spring L(free)	=100mm
Number of active coils n(a)	=3
Number of total coils	=5
Solid height L (solid)	=100mm
Types of ends	= closed and ground
Spring index (c)	=4

6.0 Calculation for Dampers

We're designing a shock absorber system to handle the impact of a vehicle weighing between 1620 kg and 2180 kg (including up to 7 passengers), travelling at 90 km/h (25 m/s) with a 56 kW engine. We're using four shock absorbers made of EN24 steel (with a tensile strength of 800 MPa) and a safety factor of 1.5, allowing for a maximum stress of 533.33 MPa.

The shock absorbers are designed to absorb a total energy of 170,323 Nm per stroke and handle a maximum reaction force of 53,786,194.7 N. Assuming only two shock absorbers are active during a severe impact, each damper must withstand a force of 26,893 N.

With a piston diameter of 100 mm, the piston area is 7,853.98 mm². This results in a design pressure of 3.42 MPa (34.2 bar). The piston rod diameter is 63 mm, and the cylinder dimensions are:

- Bore diameter: 100 mm

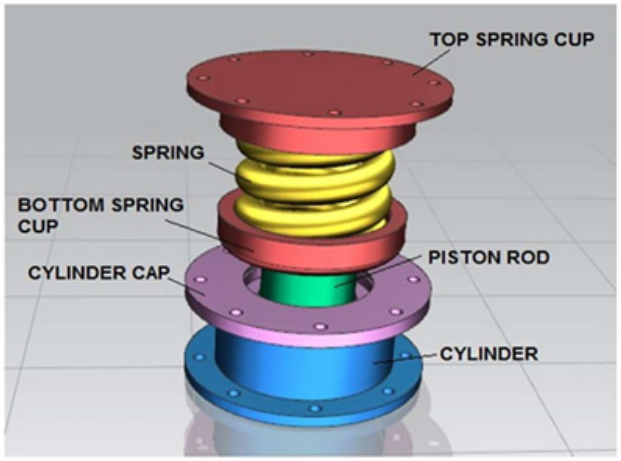


Figure 4. Cad model of shock absorber in NX software.

- Stroke: 45 mm (19 mm + seal thickness)
- Inside diameter: 63 mm
- Outside diameter: 85 mm
- Wall thickness: 8 mm

The CAD model of the shock-absorbing mechanism which is mounted between the bumper and chassis frontal portion for static and dynamic analysis is shown in Figure 4.

7.0 Mechanism Mounted on Chassis

7.1 Static Analysis Comparison

Static analysis of chassis without any bumper and mechanism, Static analysis of chassis with bumper and two energy absorbing mechanisms, and Static analysis of chassis with bumper and four energy absorbing mechanisms are shown in Figures 5, 6 and 7 respectively.

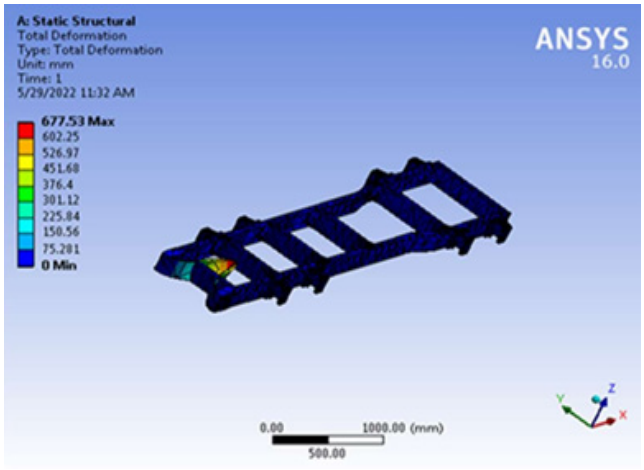


Figure 5. Static analysis of chassis without any bumper and mechanism.

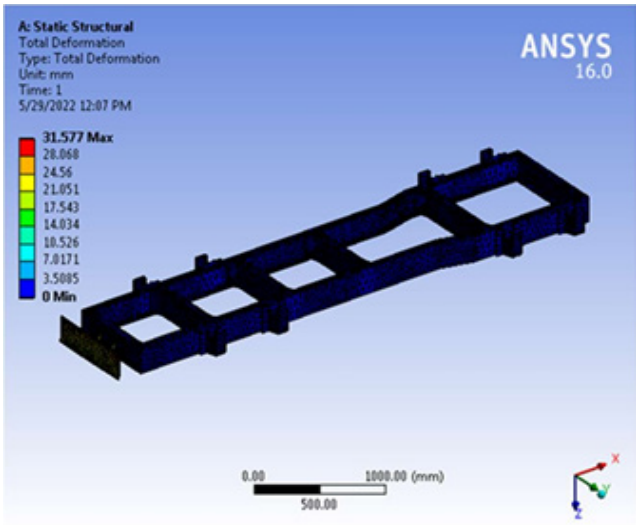


Figure 6. Static analysis of chassis with bumper and two energy-absorbing mechanisms.

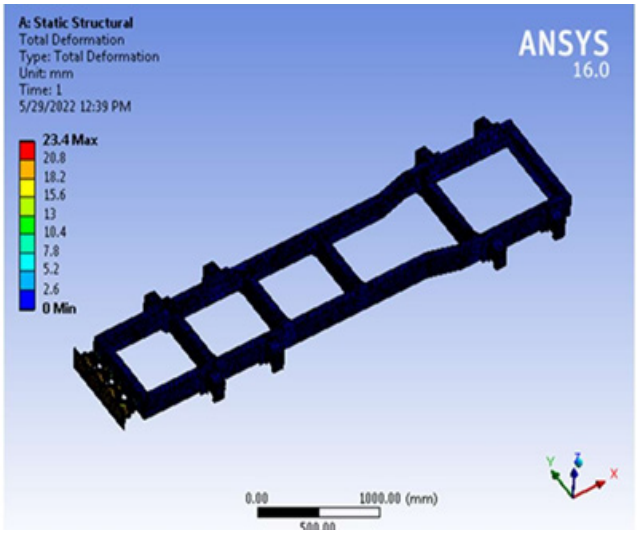


Figure 7. Static analysis of chassis with bumper and four energy-absorbing mechanisms.

7.2 Dynamic Analysis

An explicit dynamic analysis of the plain bumper system is shown in Figure 8. The deformation is observed to increase with time and the maximum deformation is 29.154 mm. Analysis with two dampers is shown in Figure 9. The total deformation observed is 18.937 mm @

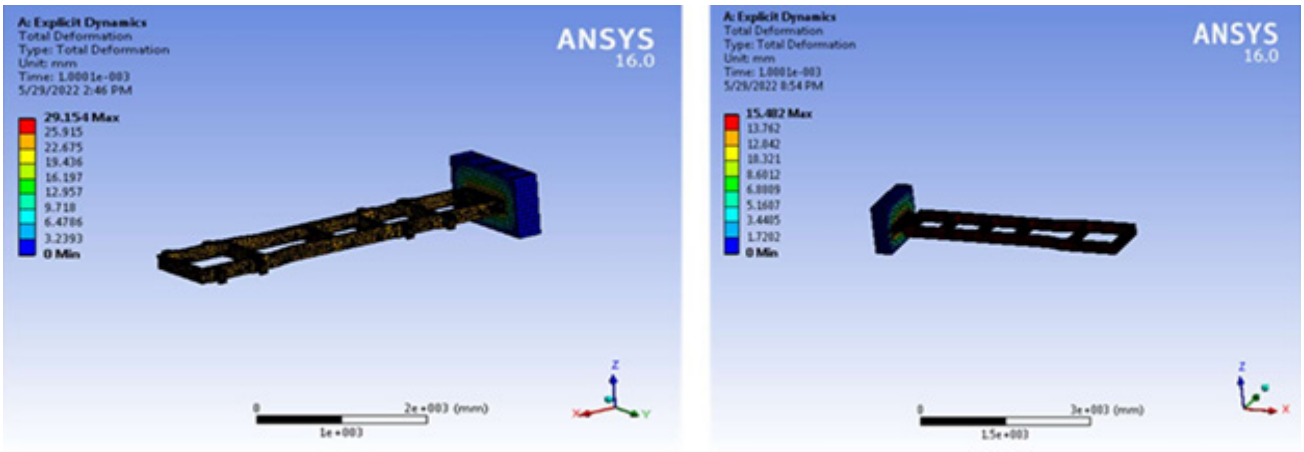


Figure 8. Explicit dynamic analysis of the plain bumper system.

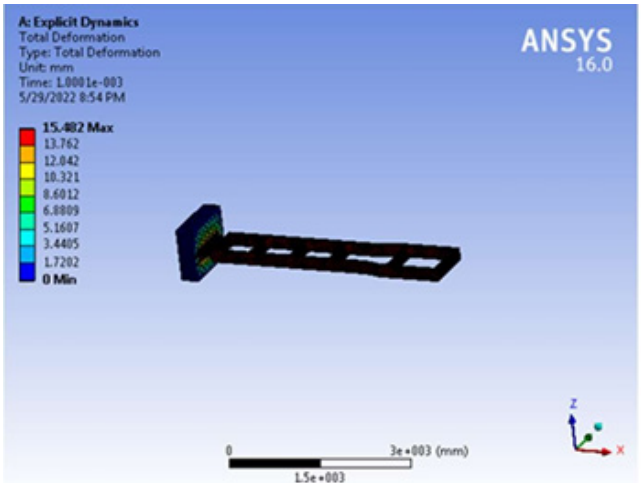


Figure 9. Analysis with only two damper mechanisms is in operation.

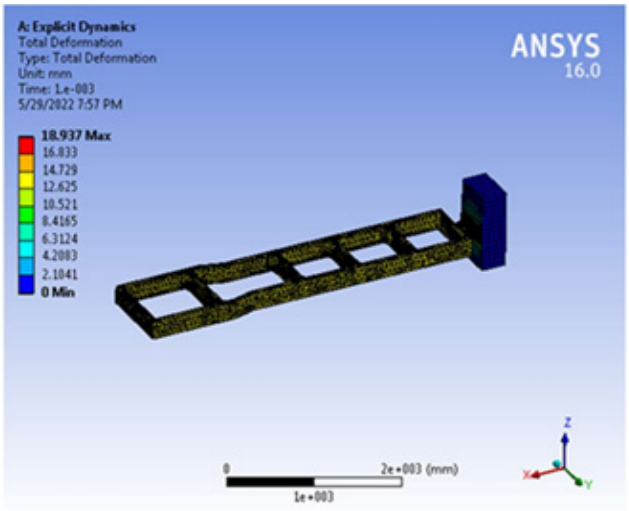


Figure 10. Analysis with four damper mechanisms is in operation.

velocity of 25m/sec (90 kmph) with two dampers. Figure 10 shows an analysis with four damper mechanisms and found total deformation observed is 15.482 mm @velocity of 25m/sec (90 kmph)

8.0 Results

8.1 Static Analysis

It can be observed that the maximum deformation in the plain bumper is 677.53 mm is highestfollowed by 31.57 mm in the two-damper system and at least 21.4 mm in the four-damper system as explained in Figure 11.

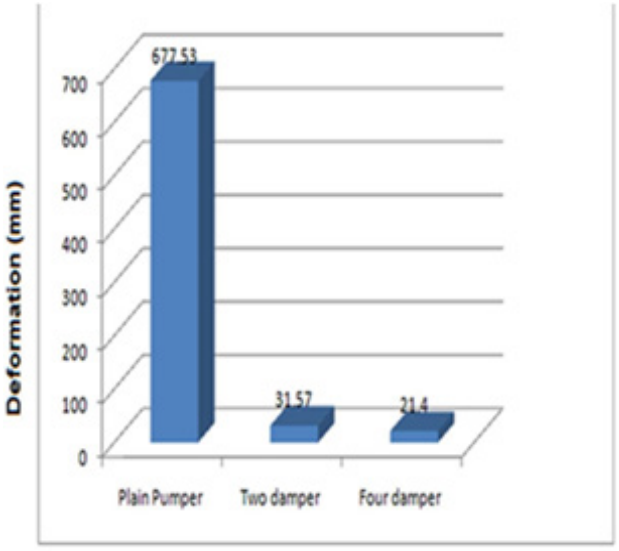


Figure 11. Deformations in plane bumpers, two dampers and four dampers for static analysis.

8.2 Dynamic Analysis

It can be observed that the maximum deformation in the plain bumper is 29.14 mm, which is the highest followed by 18.937 mm in the two-damper system and at least 15.482 mm in the four-damper system as shown in Figure 12.

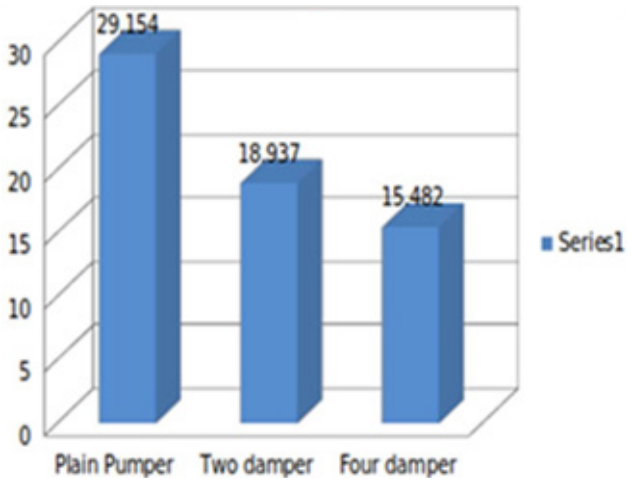


Figure 12. Deformations in plane bumpers, two dampers and four dampers for dynamic analysis.

9.0 Conclusion

The bumper is a crucial safety component of a vehicle. It's designed to absorb impact energy reduce damage to the vehicle and protect its occupants. By incorporating a damper system into the bumper design, we can further enhance its energy absorption capabilities. This system can significantly reduce deformation, as demonstrated by the comparison:

- Plain Bumper: Maximum deformation of 29.14 mm.
- Two-Damper System: Maximum deformation of 18.937 mm.
- Four-Damper System: Maximum deformation of 15.482 mm.

With a 42.44% reduction in deformation, the four-damper system offers the best protection for the vehicle and its passengers.

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