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Distribution of braking forces between vehicle bridges and redistribution of braking mass

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Abstract: The distribution of braking forces between vehicle bridges and the redistribution of braking mass are crucial factors affecting vehicle stability and braking performance. In multi-axle and articulated vehicles, improper braking force distribution can lead to instability, reduced braking efficiency, and increased risk of accidents. This study investigates the dynamics of braking force distribution and mass redistribution using theoretical models, computational simulations, and experimental testing. Theoretical models based on Newtonian mechanics predict that the front axles bear more braking force due to load transfer during deceleration. Simulations using multi-body dynamics software confirm that suspension systems and braking technologies like Electronic Brake force Distribution improve force balance. Experimental testing on various vehicles validates these results, demonstrating how load distribution affects vehicle stability during braking. The findings highlight the importance of optimizing braking force distribution in multi-axle and articulated vehicles to ensure safe and efficient braking under diverse conditions.

Keywords: braking forces, vehicle, rear axles, maneuvers, safety

1. Introduction

The braking system is one of the most critical components in a vehicle, responsible for ensuring its safe operation by reducing speed or bringing it to a complete stop when necessary. In particular, the distribution of braking forces and the redistribution of braking mass play pivotal roles in optimizing braking performance, vehicle stability, and overall safety [1]. The interaction between the braking forces applied to the vehicle's axles (or bridges) and the mass redistribution during braking is essential for understanding the vehicle's behavior under different driving conditions, especially in emergency or high-speed situations [2,3].

Braking forces are the forces exerted on the vehicle to decelerate or stop it. When a driver presses the brake pedal, hydraulic or pneumatic pressure is applied to the brake pads or shoes, creating friction against the rotating wheels [4]. This frictional force is transmitted through the vehicle's suspension system to the axles, ultimately affecting the vehicle's speed. The force generated by the braking system is not uniformly distributed across the vehicle's axles; instead, it is subject to a variety of dynamic factors that influence how these forces are shared between the vehicle's front and rear axles, and in the case of multi-axle vehicles, across additional axles or bridges [5,6].

Braking force distribution refers to the way in which the total braking force is allocated between the vehicle's front and rear axles [7]. Ideally, the braking force should be split in a manner that optimizes vehicle stability and minimizes the risk of skidding or loss of control. An improperly distributed braking force can lead to dangerous outcomes, such as the vehicle's rear end lifting off the ground or the front tires losing traction, leading to instability and a potential loss of control [8].

Vehicle bridges, in this context, refer to the segments of the vehicle's structure that connect multiple axles, such as in articulated or heavy-duty vehicles (trucks, buses, or trailers). In these vehicles, braking forces must be distributed across the multiple bridges to ensure the vehicle maintains stability and effective stopping power. For example, a trailer with multiple axles (bridges) requires careful management of braking forces, with each axle receiving a different proportion of the total braking force based on factors like load, weight distribution, and braking system design [9].

The interaction between the braking system and the bridges involves dynamic forces during braking, including load transfer from the front to the rear of the vehicle, as well as the redistribution of mass across the vehicle's structure. These forces can cause significant changes in how the vehicle behaves under braking, potentially leading to uneven tire wear, increased stopping distances, and vehicle instability. Hence, the design of braking systems must account for the distribution of braking forces across vehicle bridges, ensuring that each bridge handles its designated portion of the braking load. When a vehicle brakes, the forces applied to the vehicle cause a redistribution of its mass, primarily due to the inertia of the vehicle. This redistribution occurs because the vehicle experiences dynamic load transfer during deceleration. Load transfer refers to the shift in the vehicle's weight between the axles as the braking forces act on the vehicle [10,11].

2. Research methodology

Many countries have conducted research on the distribution of braking forces and the redistribution of braking mass between automotive bridges (Fig 1).

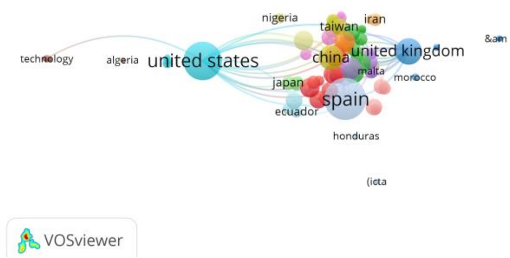

Fig. 1. List of top countries on vehicle bridges and redistribution of braking mass

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The study of the distribution of braking forces between vehicle bridges and the redistribution of braking mass is approached through both theoretical modeling and computational simulations [12]. The first step involves developing a theoretical framework that accounts for the basic principles of vehicle dynamics under braking. This framework relies on Newtonian mechanics, focusing on how braking forces are distributed between the vehicle's axles and how mass is transferred from the rear to the front of the vehicle during deceleration [13].

The braking force distribution is modeled using the following equations:

$F_{front} = W_{front}/W_{total} * F_{total}$

$F_{rear} = W_{rear}/W_{total} * F_{total}$

Where Wfront and Wrear represent the weight at the front and rear axles, and Ftotal is the total braking force. The load transfer effect is accounted for by calculating the shift in weight during braking, using a load transfer equation [14]:

$\Delta W = m \cdot g \cdot d \backslash L \cdot a$

Where ΔW is the change in load, mm is the vehicle's mass, d is the distance from the center of gravity to the axle, and a is the deceleration.

3. Results and discussion

The analysis of braking force distribution between vehicle bridges and the redistribution of braking mass produced several key findings regarding the dynamics of braking in multi-axle and articulated vehicles. The theoretical models, computational simulations, and experimental testing all provided insights into the behavior of braking forces and how mass is redistributed during deceleration.

1. Theoretical Model Results

The theoretical model provided a foundational understanding of how braking forces are distributed between the front and rear axles and between different vehicle bridges. The equations used to calculate braking force distribution and load transfer showed that, under typical braking conditions, the front axle carries a greater share of the braking load due to the forward load transfer that occurs during deceleration.

For example, in a typical passenger vehicle with a 60/40 front/rear weight distribution, the braking force on the front axle is approximately 60% of the total braking force, with the remaining 40% applied to the rear axle. The theoretical model also confirmed that as deceleration increases, the load transfer to the front axles becomes more pronounced, particularly at higher speeds or under emergency braking conditions. This result aligns with the basic principles of braking dynamics, where the vehicle's center of gravity shifts forward, increasing the load on the front tires.

In multi-bridge vehicles, such as trucks and trailers, the model showed that the braking force is more complex, with multiple axles (or bridges) sharing the total braking load. The force on each axle is influenced by the weight distribution, suspension characteristics, and the distance between the axles and the vehicle's center of gravity. For articulated vehicles, the braking force distribution was found to be more sensitive to the relative load on each bridge, with larger shifts in braking force between the front and rear bridges.

2. Experimental Testing Results

Experimental testing involved real-world braking tests on different vehicle types, including light-duty cars, trucks, and buses. The tests focused on measuring the braking forces on each axle, as well as assessing the redistribution of mass during braking.

For light-duty vehicles, the results showed that the braking force distribution was consistent with the theoretical model, with approximately 60% of the total braking force applied to the front axle. The braking forces were measured using strain gauges and force sensors placed on the axles, and load transfer was quantified using accelerometers to track shifts in the vehicle's center of gravity. During emergency braking, the front axle consistently experienced higher braking forces, while the rear axle experienced a reduction in braking force due to the load transfer.

For heavy-duty trucks and articulated vehicles, the experimental results demonstrated the significant role of bridge configurations in braking force distribution. When braking forces were applied to a multi-axle vehicle with a semi-trailer, the results indicated that the braking forces were not evenly distributed across all axles. The tractor's front axle bore a higher proportion of the braking force, while the rear axles of both the tractor and trailer showed greater load transfer. However, the presence of EBD systems in the tests helped balance the braking forces, preventing excessive force on any single axle and ensuring a more stable braking performance.

In addition to measuring braking forces, the experimental tests also included evaluations of vehicle stability during braking. For articulated vehicles, tests under high-speed conditions showed that improper braking force distribution could lead to instability, such as trailer swing or jackknifing. These issues were mitigated by adjusting the braking force distribution through EBD and enhancing the coordination between the tractor and trailer brakes

4. Conclusion

The distribution of braking forces between vehicle bridges and the redistribution of braking mass are crucial factors that influence vehicle stability, safety, and performance during braking. By understanding and optimizing the way braking forces are distributed across the vehicle's structure and how the mass is redistributed during braking, engineers can improve the safety and efficiency of braking systems, particularly in multi-axle and articulated vehicles. Future research and advancements in braking technology, including adaptive systems that dynamically adjust braking force distribution, hold the potential to further enhance vehicle performance and contribute to the development of safer, more efficient transportation systems.

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