

A Review on Air Suspension System Product Design for Commercial Vehicle Applications

C. M. Mona Lancy

Member, IEEE, S. Apurvaa Krishnaa, Member, IEEE

Abstract— Suspensions play a crucial role in vehicle comfort and handling. Different types of suspensions have been proposed to address essential comfort and handling requirements of vehicles. The conventional air suspension systems use a single flexible rubber airbag to transfer the chassis load to the wheels. In this type of air suspensions, the chassis height can be controlled by further inflating the airbag. However, the suspension stiffness is not controllable, it depends on the airbag volume and chassis load. A recent development in the air suspension includes two air chambers allowing independent ride height and stiffness tuning. In this air suspension system, stiffness and ride height of the vehicle can be simultaneously altered for different driving conditions by controlling the air pressure in the two air chambers. This allows the vehicle's natural frequency and height to be adjusted according to the load and road conditions. In this paper, a review of air suspension system product design and optimization of an air suspension design with ride height and stiffness tuning has been discussed.

Index Terms— Air Suspension System, Spring Stiffness Tuning, Ride Height Optimization

I. INTRODUCTION

Air suspension systems are the pivotal components of modern commercial vehicles, offering an array of benefits that includes improved ride comfort, load distribution and vehicle stability. But their design is not a one size fits all propositions. Namely the optimal height of the air bellows plays a defining role in maintaining a proper ground clearance and vehicle stability. This is highly significant with respect to commercial vehicles, as variations in load and road conditions can significantly impact the performance of the suspension system. Stiffness tuning of air suspension components including air springs, dampers and anti-roll bars, is another crucial aspect. Achieving the right balance between ride comfort and vehicle stability is not an easy task. Stiffness tuning allows for customization, ensuring that the suspension system can adapt to different loads and

road conditions, a critical consideration for commercial vehicles. By understanding and optimizing these factors, the manufacturers can enhance the performance, safety and reliability of air suspension systems, ushering in a new era of commercial vehicle design and performance.

II. DESIGN DETAILS OF AIR SUSPENSION SYSTEM

For the designing of air suspension system for commercial vehicles we are going to consider two crucial parameters: air bellow height for ride height control and stiffness tuning. These two parameters highly influence the overall performance, comfort, safety of the vehicle for the terrain conditions like Indian roads.

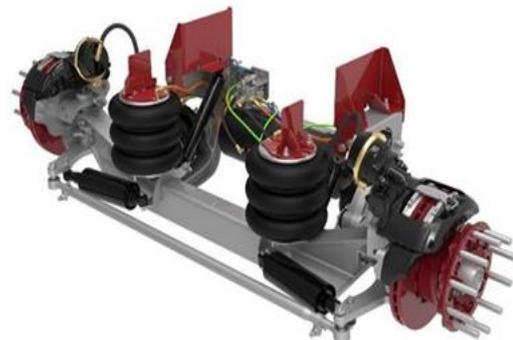


Fig. 1. Air Suspension System of a Truck

Let's take a closer look into designing of air bellow height optimization, stiffness tuning and the sensor calibration and integration of user interface.

1. Air Bellow Height Optimization:

Air bellow height optimization is performed keeping in mind the selection of suitable air bellows, load sensing system and adaptive height control.

1.1. Selecting the suitable air bellow type

For optimizing air bellow height it's essential to choose the appropriate type of air bellow with respect to vehicle type and application, namely single or

double convolute air bellows. It has to be chosen based on vehicle's weight, load distribution and ground clearance requirements. Single convolute bellows are preferred for comparatively light duty vehicles, whereas double or triple bellows are used for heavier loads.

1.2. Load sensing and control

It is incorporated to maintain ride height across varying loads. Load sensors are placed strategically to monitor ride height across varying loads, monitor the vehicle's weight distribution. Based on the feedback from these sensors, the air suspension system adjusts the air pressure in bellows to keep the vehicle at the desired ride height. This stabilizes the vehicle by ensuring optimal ground clearance.

1.3. Adaptive ride height control

To facilitate navigation challenging road conditions, adaptive ride height control is used. It allows the vehicle to automatically raise or lower itself in response to obstacles. This prevents bottoming out and enhances ride comfort while safeguarding the vehicle from potential damage.

Now let's take a closer look into spring stiffness tuning.

2. Stiffness Tuning:

The stiffness of air bellows is tuned by altering the stiffness of air spring and by controlling damping.

2.1. Air Spring Stiffness

Air spring stiffness is adjusted by adjusting the air pressure in the air springs. Higher air pressure increases stiffness providing better load bearing capacity and stability, whereas lower pressure results in a softer ride. Stiffness tuning can be manual, semi-automatic or fully automated depending on the sophistication of the system.

2.2. Damping control

Damping control complements air spring stiffness tuning the rate at which the suspension compresses and rebounds. Adjustable shock absorbers or dampers are integrated into the system to fine tune the vehicle's ride characteristics. Stiffer damping provides better control over vehicle movements and softer damping enhances ride comforts.

3. Integration and calibration:

The integration of various systems and ensuring accurate calibration while providing a user-friendly

interface is highly essential for optimizing ride height and stiffness.

3.1 Sensor calibration

Accurate sensor calibration is essential to ensure that air suspension system function optimally. Load sensors, Height sensors and Accelerometers are used for system control.

3.2. User interface

For end users and drivers, an intuitive user interface can provide the ability to manually adjust ride height and stiffness settings when necessary. Additionally, the interference can display important information related to the air suspension system's status. Further let's take a look into the drivability conditions for the Indian roads.

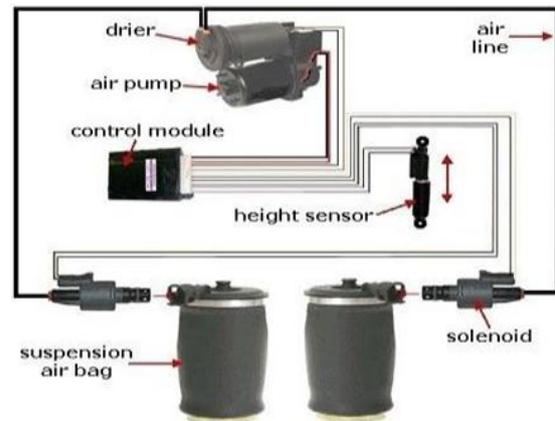


Fig. 2. Components of an Air Suspension System

III. DRIVABILITY CONDITIONS FOR INDIAN ROADS

Designing an air suspension system for commercial vehicles operating on Indian roads needs careful consideration due to unique drivability conditions prevalent in our country. Indian roads are diverse ranging from smooth highways to pothole ridden urban streets and unpaved rural paths. In such challenging environments optimizing air bellows height and stiffness tuning becomes paramount. By setting the air bellows height at an adaptable level, the suspension system can automatically adjust to varying road conditions. This adaptability ensures that the vehicle maintains a safe and comfortable ride height, avoiding potential collisions with road obstacles. Stiffness tuning plays a vital role in addressing the dynamic challenges posed by Indian roads. Conversely, during high-speed highway travel, stiffer settings improve stability and control, enhancing the overall driving experience. The ability to dynamically adjust stiffness based on road

conditions ensures optimal performance and passenger comfort, regardless of the terrain. Indian commercial vehicles often experience significant variations in load, from full cargo loads to empty returns. The air suspension system's adaptability to these load changes is crucial. Load sensors integrated into the system can detect changes in weight distribution and automatically adjust air bellow height and stiffness settings accordingly.

This adaptability ensures consistent ride quality and stability, regardless of the payload, enhancing both safety and comfort for passengers and cargo alike. Indian roads are characterized by congested traffic and narrow lanes. The air suspension system's design should allow for a tight turning radius and enhanced maneuverability. Optimizing air bellow height and stiffness ensures that the vehicle remains agile, making it easier to navigate through crowded urban areas, sharp turns and narrow alleys, enhancing overall drivability in diverse road conditions. Considering all these manufacturers must offer vehicles that excel in the demanding and diverse driving conditions of the country. Also, for the prevalent road conditions an extensive testing and multiple failure analysis is to be performed to ensure it can withstand all odd driving conditions.

IV. TESTING REQUIREMENTS AND FAILURE MODES ANALYSIS

Testing plays a key role in ensuring the safety, reliability and performance of air suspension system with main focus on optimizing air bellow height for ride height control and stiffness testing. Rigorous testing procedures are essential for validation of design, functionality and adherence to some specific parameters. Here we shall explore the testing modes which are essential for a comprehensive evaluation of air suspension system.

TESTING REQUIREMENTS

1. Component Testing:

Testing the components of the air suspension system is vital to ensure proper system in all conditions. This testing includes the following,

1.1. Air Bellows Testing

Air bellows, the core component of the air suspension system undergoes various tests to evaluate its performance and durability which includes inflation and

deflation cycles to assess the bellow's ability to maintain the air pressure and system's structural integrity over time.

1.2. Load Sensing System

The load sensors are subjected to load and calibration application tests to ensure accurate weight measurement. The sensitivity and reliability of load sensors are essential to maintain the ride height.

1.3. Damping and Shock Absorber Testing

Shock absorbers and dampers are tested to ensure the system's ability to control the suspension's motion. This includes compression and rebound assessments at various load and speed conditions.

2. Vehicle Level Testing:

This testing involves testing the level of synchronization of the air suspension system with the vehicle and studying its adaptability.

2.1. Ride Height Calibration

A crucial step in vehicle level testing is calibrating the ride height sensors. This calibration makes sure that the suspension system can accurately maintain the desired ride height under various load conditions.

2.2. Load Distribution Testing

Load distribution tests are conducted by adding different loads to the vehicle and the system's ability to distribute the weight evenly across the axles is observed, load sensing must ensure optimal load balance.

2.3. Road Test Drive

Vehicles with air suspension system are tested on various road surfaces to evaluate their performance under real world conditions. This includes uneven roads, speed bumps and rough terrains.

Here importantly the adaptive ride height control should respond effectively to the changes in the road condition.

3. Field Testing

This testing involves testing the vehicle along with its air suspension system at real time in extreme conditions over varied time periods.

3.1. Extreme conditions testing

The air suspension system is tested in extreme conditions such as humidity, salt corrosion, extreme temperatures, heavy rainfall to assess the system's resistance and reliability even in challenging environments.

3.2. Long Term Testing

Long term testing involves running the system over a prolonged period to monitor its performance, safety and longevity of components which helps to identify potential wear and tear issues that may not be apparent in short duration conducted tests.



Fig. 3. Air bags in Air Suspension System



Fig. 4. Air bags under extreme temperature

FAILURE MODES ANALYSIS

A comprehensive understanding of the failure of air suspension system is vital for the evaluation of design and improvisation in testing with a focus on optimizing air bellow height for ride height control and stiffness tuning. Addressing these potential failures ensures safety, reliability and durability of the system. This analysis will explore the common failure modes and how the previously discussed testing modes can help mitigate these issues. Let's take a closer look into various failures and the suitable measures to overcome them.

1. Air Bellow Failures:

1.1. Bellow Punctures

One of the critical failure modes is the puncture of air bellows. This can occur due to sharp objects lying on the road or the excessive stress on the bellows. [20]

One of the suitable measures to overcome it is to incorporate non pneumatic, airless tire technology which replaces traditional air-filled bellows with a solid, puncture resistant structure which eliminates sag, decreases vibration and stabilizes sway.

1.2. Air leaks

It can occur from small cracks, loose fittings or deteriorating seals. The gradual loss of air pressure can lead to reduced ride height and compromise in the suspension system performance. It can be reduced by incorporating a kind of self-inflating mechanism which monitors the air pressure in the airbag continuously and tops it up when required. If the system detects a loss of air, it can automatically compensate for air leakage maintaining the correct ride height and performance. Also, we can design air bellows, fittings with self-sealing properties.

2. Load Sensing System Failures:

2.1. Sensor Drift and calibration errors

Load sensors may experience drift resulting in inaccurate weight measurements, improper ride height adjustments. Incorrect sensor calibration may lead to inaccurate data and adjustments of the air suspension system.

3. Damping and Shock Absorber Failures:

3.1. Damper Leakage, Wear and fatigue

Leakage of damping fluid from shock absorbers may lead to poor shock absorption, uncomfortable rides and reduced stability. Also, dampers experience wear and fatigue over time affecting their ability to control the suspension's motion effectively. By conducting thorough testing, manufacturers can identify and prevent the above discussed failure modes. The testing modes not only validate the system's design but also help in early detection of the potential issues.

V. CONCLUSION

This comprehensive approach involving design parameters, drivability considerations, testing and failure mode analysis of air suspension systems with a specific focus on air bellow height optimization and stiffness tuning aims to enhance the performance and reliability of commercial vehicles. Design considerations set foundations for maintaining ride height and load distribution while the drivability conditions particular in our challenging Indian roads necessitate the adaptive air suspension systems. Rigorous testing modes ensure functionality under

real world conditions and failure modes analysis identifies and addresses the potential issues, increasing safety, system longevity. By integrating all these components, we get air suspension system optimized for reliability, safety and superior comfort in diverse commercial vehicle applications.



C. M. Mona Lancy (Fellow, IEEE Robotics & Automation Society)
monalancy@gmail.com
Department of Mechatronics Engineering,
Rajalakshmi Engineering College, Chennai, India

REFERENCES

- [1] Gaurav Vaidya, Pranay Kanoje, Nikhil Tidke, "Advancement in Suspension System for Automobile Industry: A Review", IJETSR, Volume 4, Issue 9
- [2] Ashish Gorde, Siddharth Salve, "Comfort Analysis of Modern Active Air Suspension System", IJRSET, Jun 2020, e-ISSN: 2319-8753, p-ISSN: 2320-6710
- [3] Abhishek Goyal, Ashish Sharma, "Advances in Active Suspension System", IJCRT, Dec 2017, ISSN: 2320-2882
- [4] Bollishetty, Sreedhar, Chandrakant Deshmukh, "A Simplified Model of Air Suspension for Multi Body Simulation of the Commercial Passenger Vehicle", SAE International 2013-26-0157, Nov 2013, e-ISSN: 2688-3627, DOI: <https://doi.org/10.4271/2013-26-0157>
- [5] Suchit Naresh Moon, "Active Air Suspension System", IJSRD Volume 6, Issue 05, 2018, ISSN (online): 2321-0613
- [6] Aizuddin Fahmi Mohd Riduan, Noreffendy Tamaldin, Ajat Sudrajat, Fauzi Ahmad, "Review on active suspension system", SHS Web of Conferences 49(23):02008, January 2018, DOI:10.1051/shsconf/20184902008
- [7] Naveen Sankar G M, Manikanthan R, Anshadh, "Adaptive Air Suspension in Automobiles: A Case Study", Kerala Technological Congress (KETCON-2016 Technology for Sustainability), 2016
- [8] Kamran Ikram et al., "Development of Active Air Suspension System for Small Agricultural Vehicles", Big Data Agriculture (BDA) 2(2) (2020) 41-46, 2020, ISSN: 2682-7786
- [9] Goftila Gudeta Sirata, Iyasu Tafese Jiregna, "A Review of the Vehicle Suspension System", Research Gate, June 2020, ISSN (Online): 2544-1671, DOI: 10.30464/jmee.2020.4.2.109
- [10] An adaptive pneumatic suspension system for improving ride comfort and handling, Journal of Vibration and Control 22(6), June 2014, DOI:10.1177/1077546314539717

S. Apurvaa Krishnaa, (Member, IEEE Robotics & Automation Society) apurvaa004@gmail.com
Department of Mechatronics Engineering,
Rajalakshmi Engineering College, Chennai, India