

# A Review of the Steering Column: Corrosion, Wear, and Mechanical Damage

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<sup>1</sup>Vitalijus Rudzinskas , <sup>2</sup>Virginijus Daugėla, <sup>3</sup>Mantas Juchnevičius and <sup>\*4</sup>Oleksandr Kapustynskyi 

<sup>1</sup>Associate Professor, Vilniaus kolegija, Department of Mechanical Engineering (Lithuania)

<sup>2</sup>Lecturer, Vilniaus kolegija, Department of Mechanical Engineering (Lithuania)

<sup>3</sup>Lecturer, Vilniaus kolegija, Department of Mechanical Engineering (Lithuania)

<sup>4</sup>Associate Professor, Vilnius Gediminas Technical University, Faculty of Mechanics (Lithuania)

**Abstract:** The steering column is a critical component of modern vehicles, directly affecting driving safety and comfort. This article examines the primary factors that influence steering column performance, including corrosion, wear, and mechanical damage, under various operational and environmental conditions. Common failure modes, such as backlash, noise, and bearing seizure, are analyzed, highlighting the importance of timely diagnosis to prevent accidents and costly repairs. The study details a repair process for corroded bearings, demonstrating its effectiveness through vibration and torque tests. Advances in materials, sealing technologies, and predictive maintenance are discussed as strategies to enhance durability. The findings underscore the need for ongoing research to improve steering system reliability, particularly as vehicles evolve toward electrification and autonomy.

**Keywords:** steering column, vehicle safety, predictive maintenance, vibration analysis

## 1 | INTRODUCTION

Modern vehicles, from compact city cars to heavy duty long-haul trucks, play a significant role in the economic and social development of society [1]. As the intensity of traffic increases and vehicle designs become more complex, particular emphasis is placed on the safety and durability of the components. One of the critical parts of every vehicle that directly impacts driving safety and comfort, is the steering column (Figure 1).

### \*Corresponding Author

Oleksandr Kapustynskyi, Associate Professor, Vilnius Gediminas Technical University, Faculty of Mechanics (Lithuania)  
Email: o.kapustynskyi@vilniustech.lt

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*Fig. 1. Electric steering column [2].*

In its fundamental operation, the steering column transfers force from the steering wheel to the wheel control mechanisms, while a power steering system (hydraulic or electric) reduces the physical effort required from the driver. This technology simplifies maneuvering in challenging conditions, such as parking or avoiding obstacles, while improving the precision and stability of vehicle control, improving responsiveness to steering input [3]. Despite stringent requirements for the quality of the assembly and materials, steering systems are prone to natural wear and potential failures due to a combination of operational factors, including environmental conditions, road surface quality, maintenance standards, and driving patterns (eg, frequent acceleration, braking, corrosion, impacts, and vibrations). The timely diagnosis of the fault is crucial, as a defective steering column can lead to accidents and substantial repair costs [4].

During daily vehicle use, whether for personal or commercial purposes, the steering column is subjected to significant dynamic loads and vibrations. Sudden temperature changes, high humidity, and road chemicals can contribute to the formation of corrosion within the mechanism. Damage or wear to sealing components, such as rubber boots or clamps, often allows moisture to enter internal cavities, leading to corrosion of moving parts such as bearings, bushings, and shafts. This can result in typical failure symptoms, including steering wheel play, uneven operation, squeaking or humming noises, increased effort required to turn the wheel, and, in severe cases, complete column lockup [5].

The importance of research to improve the reliability of the steering mechanism is supported by statistics, indicating that steering system failures are among the most dangerous and common causes of accidents related to the technical condition [6]. Meanwhile, the intensity of modern traffic flows and the increased road safety requirements encourage manufacturers to develop innovative designs and enhance the materials used in steering column production.

The evolution of steering systems is closely related to the need to improve vehicle control, safety, and driver comfort. Early vehicles relied on manual steering, which demanded considerable physical effort, particularly at low speeds or when stationary. The introduction of hydraulic power steering in the mid-20th century marked a significant advancement, greatly reducing driver effort through hydraulic pressure. In recent decades, electric power steering (EPS) systems have gained widespread adoption due to their advantages, such as reduced weight, improved fuel efficiency, and compatibility with advanced driver assistance systems (ADAS).

A promising development is steer-by-wire technology, which eliminates the mechanical connection between the steering wheel and the wheels, offering new possibilities for vehicle design and dynamic performance. For instance, in autonomous vehicles, steer-by-wire can enable more precise control and integration with automated systems. However, this technology faces challenges related to reliability and cybersecurity, making it a key focus of ongoing research.

Despite these advances, steering systems remain susceptible to wear and failure under harsh operating conditions. Road quality, driving style, and environmental factors accelerate component degradation. For example, potholes and uneven surfaces create significant stress on steering mechanisms, leading to premature wear. Moisture, salt, and other corrosive agents can compromise the integrity of seals and metal parts.

To address these challenges, manufacturers and researchers are developing strategies to improve steering system durability and performance. These include the use of stronger materials, such as composites and corrosion-resistant alloys, as well as predictive maintenance technologies. For example, sensors embedded in steering components can monitor wear and alert drivers to potential problems before they escalate. Integration with vehicle dynamics control systems, such as electronic stability control (ESC), further improves safety by maintaining control in emergency situations.

As the automotive industry progresses toward electrification and autonomy, the role of steering systems will evolve, but their fundamental importance to safety and driver satisfaction will remain unchanged. The purpose of this article is to examine the main factors that affect steering column performance, considering operational and environmental conditions, and to explore modern methods for repairing faults.

## 2 | PROBLEM FORMULATION

A faulty steering column can often be identified by a distinctive knocking sound or other auditory symptoms, indicating various underlying problems. Common causes include:

- Gaps between gear teeth, resulting from corrosion or wear, leading to imprecise control and increased steering effort.
- Loose fasteners in the steering mechanism, causing excessive movement and noise. Regular inspection and tightening of bolts and nuts to specified torque values can prevent this problem.
- Backlash, manifested as unwanted noise in the steering column, often due to worn gears or connections and exacerbated by corrosion.
- Corrosion, which can contribute to backlash and affect the functionality of the mechanism.
- Wear of the plastic support bushing, leading to noise and reduced control precision.
- Damage to rubber protective boots, allowing dirt, dust, and moisture to enter the mechanism, accelerating the wear of the rack and sliding supports.

The corrosion of internal components typically arises from inadequate sealing. Rubber seals on the sides and fasteners that secure them maintain the stability of the column. If any of these components fail, the seal is compromised and moisture is likely to penetrate, causing corrosion (Figures 2, 3). The hum of the column or jamming is frequently linked to a rusted bearing (Figure 4).



*Fig. 2. Protective rubber with moisture entering.*



*Fig. 3. Corrosion-affected column.*



*Fig. 4. Under the left rusty inner part of the bearing. Under the right-repaired inner part of the bearing.*

Corrosion is particularly hazardous, as it can develop unnoticed within the mechanism, causing significant damage over time. Moisture ingress, often due to damaged seals, creates conditions for oxidation of metal parts, reducing their strength and increasing friction. Bearings are especially vulnerable: corrosion can cause them to seize, resulting in humming or complete steering column lockup, posing a critical safety risk.

Preventive measures are essential to mitigate these risks. Regular seal and boots, timely replacement of worn parts, and the use of corrosion-resistant materials are critical steps. For example, incorporating stainless steel or protective coatings for metal components can significantly reduce rust formation. Advances in sealing technology, such as more durable boots, also contribute to extending the useful life of steering systems.

In addition, wear and damage are often linked to operating conditions. Driving on rough roads or adopting an aggressive driving style accelerates mechanical degradation. Studies suggest that routine maintenance, including seal and lubrication, can extend the useful life of the steering column by 20-30%. Climatic factors are also significant: regions with high humidity or frequent use of road de-icing chemicals face an elevated risk of corrosion.

Understanding the typical failure modes of steering columns and their causes is vital for effective diagnosis and repair. Prompt problem resolution and preventive measures help to maintain the reliability and safety of the steering system.

### 3 | RESULTS AND DISCUSSION

Repairing a steering column affected by corrosion or mechanical damage, particularly in the bearing area, requires high precision and adherence to strict standards. Corrosion roughens and pits the bearing surface, disrupting the lubrication efficiency. Water can mix with or completely wash away the lubricant, causing the bearing to produce unusual noises during rotation. Over time, especially after prolonged inactivity, rust can bind the bearing's inner and outer rings, rendering it immobile, necessitating replacement and a thorough mechanism inspection.

In many modern vehicles, the steering column bearing is designed as an integral part, and manufacturers often recommending replacement of the entire assembly in case of failure. However, this approach is costly and is not always necessary. With appropriate equipment and expertise, the bearing can be repaired, extending the service life and reducing costs.

The repair process involves the following steps:

1. Disassembly and cleaning of the bearing to remove corrosion, old lubricant, and contaminants.
2. Damage assessment to determine the appropriate repair standard.
3. Bearing inner and outer rings using precision tools to restore the surfaces according to the selected standard (Figure 5). This step requires high accuracy, as the bearings operate within tight tolerances for surface finish, dimensions, and fit.
4. Reassembly with new components: The bearing is rebuilt with new balls or rollers (often larger to compensate for the material removed during machining) and fresh lubricant (Figure 6).
5. Reintegration in the column: the repaired bearing is reinstalled into the steering column housing.



*Fig. 5. Sanding the inner part of the bearing*



*Fig. 6. Prefabricated bearing with new details*

After repair, the column is tested on a specialized bench that simulates vehicle operating conditions, including driving loads (Figure 7). The bench rotates the input shaft, applies external force through the tie rod, and measures the input shaft rotational force, the column's output force, and vibration levels. Extended testing evaluates the durability of the repair.





*Fig. 7. Prefabricated bearing with new details*

In the presented case, a column damaged in an accident initially produced vibrations of 12.5 kHz at a torque of 6 Nm, exceeding the acceptable vibration limit of 6 kHz. After bearing repair, vibrations dropped to 4.5 kHz and torque decreased to 4.8 Nm, meeting the standards (limits: 6 kHz and 6 Nm). This demonstrates the success and the feasibility of restoring the column rather than replacing it.

Vibration analysis is critical as excessive levels may indicate residual defects. Modern diagnostic tools, such as vibration spectrum analyzers, enable the precise identification of fault causes. Future advancements, including smart systems with real-time bearing condition sensors, could improve reliability through predictive maintenance.

Steering column repair is a complex but essential process for maintaining vehicle safety and performance. Precise techniques and rigorous quality control ensure an effective restoration of functionality.

#### 4 | CONCLUSIONS

The steering column is a vital vehicle component that directly influences driving safety and comfort. As demonstrated, factors such as corrosion, wear, and mechanical damage can affect the performance of the steering system, creating potential risks. The timely diagnosis and repair are essential to prevent accidents and extending vehicle lifespan.

Detailed analysis of common issues and the bearing repair process highlights the importance of precision and adherence to standards to ensure steering system reliability. The practical example shows that with proper techniques, a damaged column can be restored to perform beyond its original specifications.

Future developments, including advanced materials and predictive maintenance technologies, promise to improve the durability and safety. As vehicles move toward electrification and autonomy, the steering mechanisms will evolve, but their essential role in ensuring safety will remain constant. Ongoing research and innovation are necessary to meet the modern transportation demands.

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**Author's Biography:**

**Vitalijus Rudzinskas** is an Associate Professor at the Vilniaus kolegija, Department of Mechanical Engineering (Lithuania). His research focuses on the material engineering, and welding's.

**Virginijus Daugėla** is a lecturer at the Vilniaus kolegija, Department of Mechanical Engineering (Lithuania)

**Mantas Juchnevičius** is a lecturer at the Vilniaus kolegija, Department of Mechanical Engineering (Lithuania).

**Oleksandr Kapustynskyi** is an Associate Professor at Vilnius Gediminas Technical University, Faculty of Mechanics (Lithuania). His research focuses on the mechanical and material engineering, laser technologies, and welding's.

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