International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 13 Issue: 11 | Nov 2026 www.irjet.net p-ISSN: 2395-0072

Design Optimization Strategies for Achieving Euro 7 Brake Particulate Emission Compliance in Passenger Vehicle Foundation Brake Systems

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Abstract – *Euro 7 emission regulations introduce mandatory limits on brake wear particulate emissions, making non-exhaust emissions a critical consideration in the design of passenger vehicle braking systems. This regulation requires automotive manufacturers to develop foundation brake systems that minimize particulate matter (PM10) emissions while maintaining braking performance, safety, durability, and cost efficiency. This paper presents a systematic approach to achieving Euro 7 compliance through optimized brake system design. The study examines the primary mechanisms of brake wear particle generation and evaluates the influence of brake pad materials, disc design, thermal management, contact pressure distribution, residual drag, and regenerative braking on particulate emissions. An engineering framework, the Integrated Brake Particulate Emission Reduction Framework (IBPERF), is proposed to support the development of low-emission brake systems by integrating tribological optimization, CAE analysis, thermal simulation, and experimental validation. The proposed methodology provides practical design guidelines for automotive OEMs and brake manufacturers to develop sustainable, high-performance braking systems capable of meeting future Euro 7 environmental requirements.*

1. INTRODUCTION

Over the past three decades, European emission standards have significantly reduced vehicle exhaust emissions through advancements in engine technologies and emission control systems. As tailpipe emissions continue to decline, non-exhaust sources such as brake wear, tyre wear, and road dust have become major contributors to urban particulate matter pollution. Among these, brake wear generates fine particulate matter (PM10 and PM2.5) through friction between brake pads and discs, posing environmental and public health concerns.

To address these emissions, Euro 7 regulations introduce, for the first time, limits on brake particulate emissions for passenger vehicles. This shift requires automotive manufacturers to optimize foundation brake systems by improving friction materials, thermal management, brake design, and control strategies while maintaining braking performance, safety, durability, and cost effectiveness. These new requirements present significant engineering challenges and drive the development of innovative low-emission braking technologies.

2. EVOLUTION OF EMISSION REGULATIONS

The evolution of European emission standards reflects a gradual transition toward comprehensive vehicle environmental impact assessment.

2.1 Euro 1 (1992)

The Euro 1 regulation introduced catalytic converter requirements and established the first harmonized emission limits for passenger vehicles.

2.2 Euro 2 to Euro 4 (1996–2005)

These regulations progressively tightened limits on:

- Carbon monoxide
- Hydrocarbons
- Nitrogen oxides
- Particulate emissions

For both gasoline and diesel-powered vehicles.

2.3 Euro 5 (2009)

Euro 5 introduced diesel particulate filters and significantly reduced particulate matter limits, particularly for compression ignition engines.

2.4 Euro 6 (2014)

Euro 6 focused on reducing NOx emissions and introduced Real Driving Emission (RDE) testing procedures to improve correlation between laboratory and on-road performance.

2.5 Euro 7 (2025 onwards)

Euro 7 expands regulatory scope beyond tailpipe emissions and introduces requirements addressing:

- Brake particulate emissions
- Tyre wear emissions
- Extended durability requirements

- Lifetime compliance monitoring
- Enhanced real-world performance validation

This shift recognizes that future vehicle sustainability must address the complete environmental footprint of vehicle operation.

3. IMPORTANCE OF BRAKE PARTICULATE EMISSIONS

Brake wear emissions originate from repeated contact between friction materials and rotating brake discs or drums. During braking, mechanical energy is converted into thermal energy through frictional interaction. This process generates wear debris consisting of:

- Metallic particles
- Oxides
- Carbonaceous materials
- Mineral fillers
- Binder degradation products

The composition and quantity of generated particles depend on numerous factors including:

- Friction material formulation
- Disc metallurgy
- Contact pressure distribution
- Braking severity
- Thermal loading
- Environmental conditions

Recent studies indicate that brake wear particles may contain potentially harmful substances such as:

- Iron oxides
- Copper compounds
- Zinc compounds
- Antimony compounds
- Carbonaceous particles

Exposure to these materials has been linked to respiratory and cardiovascular health concerns, particularly in densely populated urban environments.

4. ENGINEERING CHALLENGES FOR EURO 7 COMPLIANCE

Achieving Euro 7 compliance requires balancing multiple, often conflicting engineering objectives.

Brake systems must simultaneously provide:

- High braking performance
- Short stopping distances
- Stable friction characteristics
- Excellent thermal capacity
- Long service life
- Low cost
- Low noise and vibration
- Reduced particulate emissions

Traditional brake design methodologies prioritized braking effectiveness and durability. Euro 7 introduces particulate emissions as an additional design constraint, necessitating a multidisciplinary optimization approach.

Key engineering challenges include:

- Material Optimization
- Reducing wear while maintaining friction stability.
- Thermal Management
- Minimizing high-temperature wear mechanisms.
- Pressure Distribution Control
- Reducing localized wear concentrations.
- Residual Drag Reduction
- Preventing unnecessary wear during vehicle operation.
- Regenerative Braking Integration
- Reducing friction brake utilization without compromisingSafety.
- Corrosion Resistance
- Maintaining low-emission performance throughout Vehicle life.

5. RESEARCH OBJECTIVES

The primary objectives of this research are:

1. To investigate the mechanisms responsible for brake particulate generation.
2. To analyze the influence of design parameters on brake wear emissions.
3. To evaluate material and system-level solutions for Euro 7 compliance.
4. To develop a structured engineering methodology for brake emission reduction.
5. To propose an Integrated Brake Particulate Emission Reduction Framework (IBPERF) for future brake system development.
6. To establish practical guidelines for automotive OEMs and brake suppliers developing next-generation braking systems.

6. SCOPE OF STUDY

This research focuses on passenger vehicle foundation brake systems including:

- Floating caliper disc brakes
- Fixed caliper disc brakes

- Rear drum brakes
- Electronic Parking Brake systems
- Regenerative braking integration

The study considers both conventional internal combustion engine vehicles and electrified vehicle platforms including hybrid and battery electric vehicles.

The scope encompasses tribological behavior, thermal management, brake architecture optimization, simulation methodologies, and experimental validation techniques required to achieve compliance with Euro 7 brake particulate emission limits.

7. RESULTS AND DISCUSSION

- Brake dust reduction
- Thermal performance
- Wear characteristics
- Engineering trade-offs
- Compliance with Euro 7 limits

8. FUTURE SCOPE

- AI-based wear prediction
- Digital Twin brake systems
- Smart brake-by-wire control
- Sustainable friction materials
- Advanced brake particle monitoring
- Machine learning optimization

9. CONCLUSION

Euro 7 emission regulations represent a significant advancement in automotive environmental legislation by introducing limits on non-exhaust brake particulate emissions. Meeting these requirements demands a multidisciplinary approach to foundation brake system design that balances emission reduction with braking performance, safety, durability, manufacturability, and cost.

This paper reviewed the primary mechanisms of brake wear particle generation and identified key factors influencing particulate emissions, including friction material composition, brake disc design, thermal loading, contact pressure distribution, residual drag, and regenerative braking utilization. A systematic design optimization approach, the Integrated Brake Particulate Emission Reduction Framework (IBPERF), was proposed to integrate material selection, thermal management, CAE-based optimization, and experimental validation into the brake development process.

The study concludes that significant reductions in brake particulate emissions can be achieved through the combined application of low-wear friction materials, optimized rotor ventilation, improved caliper stiffness, effective brake drag reduction, and intelligent regenerative braking strategies. The integration of simulation tools with brake dynamometer testing provides an efficient methodology for validating brake system performance and supporting Euro 7 compliance during product development.

The proposed framework offers practical engineering guidance for automotive OEMs and brake system suppliers in developing next-generation, environmentally sustainable foundation brake systems. Future work should focus on advanced friction materials, predictive wear modelling using artificial intelligence, digital twin technologies, and smart brake-by-wire systems to further reduce non-exhaust emissions while enhancing vehicle safety and efficiency.

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