DYNAMIC ANALYSIS OF LANDING GEAR WITH MR FLUID BASED DAMPER

C. Kushal Kumar[1], S.S.L. Narasimha Rao[2], Y. Ravi Kumar[3], B. Sujan[4], Vijee Kumar[5]

1,2,3,4 -Student, School of Mechanical Engineering, REVA University, Bengaluru, Karnataka, India
5-Associate Professor, School of Mechanical Engineering, REVA University, Bengaluru, Karnataka, India

ABSTRACT

The performance of aircraft landing gear is vital for ensuring safe landings and minimizing impact forces during touchdown. Traditional landing gear systems typically employ passive damping mechanisms, which lack the flexibility to adapt to varying landing conditions. To address this limitation, semi-active landing gear systems incorporating Magnetorheological (MR) fluid-based dampers offer a promising alternative.

MR fluid is a smart material whose rheological properties can be rapidly altered by applying a magnetic field, enabling real-time control of damping characteristics. In the context of aircraft landing gear, MR dampers provide a controllable, semi-active solution that can dynamically adjust energy absorption to suit different landing scenarios. This adaptability enhances both aircraft safety and passenger comfort.

This study presents a dynamic analysis of a semi-active landing gear system integrated with MR dampers. A detailed mathematical model simulates the landing impact and evaluates the performance of semi-active control strategies, such as skyhook and ground-hook control. Numerical simulations demonstrate that MR fluid-based systems significantly reduce impact loads and improve vibration attenuation compared to conventional passive systems.

The findings underscore the advantages of using MR fluid in landing gear applications, offering superior response times, tenable damping, and enhanced adaptability to unpredictable landing conditions. The study confirms that MR dampers play a crucial role in modern aircraft landing gear, pushing the boundaries of safety and performance in aerospace engineering.

Keywords – MR Fluid, Landing gears, dynamic analysis, dynamic analysis, MR dampers

1. Introduction

The word magnetorheological fluid means fluid whose apparent viscosity increases, with application of magnetic field. The magnetorheological Fluid (MR) is a typically a smart material, whose shear yield stress can be adjusted through changing the strength of external magnetic field, The changing process only takes a few milliseconds.

In the absence of a magnetic field, MR fluids behave like newtonian fluids free-flowing with low viscosity. However, when a magnetic field is applied, the suspended magnetic particles quickly align into chain-like structures along the field lines. This alignment restricts the movement of the fluid, increasing its apparent viscosity and transforming it into a semi-solid state within milliseconds. Once the magnetic field is removed, the particles return to their random arrangement, and the fluid returns to its original liquid state [1].

The research reported that MR fluids can transform between Semi-solid and liquid due to the existence of the magnetic particles; specifically, the iron particles are magnetized, and MR fluids can be changed rapidly from liquid to Semi-solid in the presence of a magnetic field, while regaining their liquid state when the magnetic field is removed [2]. The key challenge in MR fluids is maintaining the sedimentation stability of the ferromagnetic particles, as their density is much higher than that of the carrier fluid.

2. Literature Review

Pranav Gadekar.et.al. [1] This paper explores the properties, composition, and diverse applications of Magnetorheological (MR) Fluid, a smart material whose viscosity can be controlled by an external magnetic field. MR fluids consist of magnetizable particles suspended in a carrier fluid and find applications in various industries, including automotive, prosthetics, civil engineering, and military.

Thomas Leps.et.al. [2] This paper presents a high-fidelity simulation of magnetorheological (MR) fluids using the Discrete Element Method (DEM) with the LIGGGHTS framework, extended to incorporate a mutual dipole magnetic model. The study simulates MR fluids with polydisperse particle size distributions, improving accuracy in yield stress predictions compared to previous monodisperse models.

Ashish Gupta.et.al. [3] This paper investigates the dynamic behavior of heavy road vehicles under different road conditions, focusing on the effects of road irregularities such as bumps. The study uses a bond graph modeling technique to create a computational model of a heavy road vehicle with 11 degrees of freedom. The model incorporates the vehicle's cab, base frame, and suspension system, simulating the vehicle's response to various bump sizes and speeds.

Fu Li, Guan Wei.et.al. [4] This paper presents a magnetorheological (MR) buffer system for aircraft landing gear, offering adjustable damping force without requiring an external energy source. A state equation is developed, and a semi-active control strategy based on Model Predictive Control (MPC) is proposed. The control algorithm adaptively adjusts damping force to optimize landing impact absorption, overcoming limitations of traditional oleo-pneumatic systems.

Wu Dong-su.et.al. [5] This paper presents a Nonlinear Model Predictive Control (NMPC) approach using a Genetic Algorithm (GA) to optimize the damping performance of semi-active landing gear. The NMPC method adjusts damping force dynamically to enhance landing impact absorption and taxiing performance while considering actuator limitations. A simulation model and drop-test experiments validate the controller's effectiveness.

Fan Ran.et.al. [6] This research introduces a dynamic model for post-landing gear and validates the model through drop tests. The model, developed using ADAMS/Aircraft software, analyzes load distribution of each landing gear strut during symmetrical and asymmetrical landing processes.

Dr. T. Haritha.et.al. [7] The study highlights the critical role of advanced analysis techniques, such as Computational Fluid Dynamics (CFD) and stress analysis, in optimizing the design and performance of aircraft landing gear. It also emphasizes the implementation of low-noise technologies and optimal material selection, particularly titanium alloys, which enhance structural safety while addressing operational challenges like noise reduction and weight management.

Divakaran V.et.al. [8] This paper discusses the challenges in designing landing gear with minimum weight, volume, high performance, improved life, and reduced lifecycle cost. It stresses the need to reduce the design and development cycle time of landing gear while meeting safety and regulatory requirements. Several technologies have been developed to address these challenges.

Diogo Correia (D.C.).et.al. [9] This paper focuses on the dynamics of aircraft movement on the ground, exploring tire and suspension modeling, simulation software, and energy interactions with airport pavements.

A. Toloei.et.al. [10] This study presents a mathematical model and vibration analysis of an aircraft equipped with an active landing gear system. The Linear Quadratic Regulator (LQR) technique is used to optimize landing gear performance, reducing vibrations and enhancing ride comfort. A 7-degree-of-freedom (DOF) model is developed to simulate the aircraft's vertical dynamics.

Şahin Yıldırım.et.al. [11] The study explores vibration analysis and control in aircraft landing systems using neural controllers to reduce vibrations and enhance landing comfort and safety. A nonlinear aircraft landing model, considering shock absorbers and tire dynamics, is developed, with two intelligent control methods (Artificial Neural Networks (ANN) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS)) proposed.

TA Instruments.et.al. [12] This paper discusses yield stress analysis, an essential factor in understanding product performance in complex structured fluids. The research focuses on techniques such as Steady Stress Sweep (SS), Steady Rate Sweep from High to Low Shear Rates (SR), and Dynamic Stress/Strain Sweep (DS) for measuring yield stress. The SS method is particularly effective for medium viscosity materials, while SR is useful for very low viscosity materials.

Magdalena Osial.et.al. [13] This paper explains that Magnetorheological Fluids (MRFs) are classified as intelligent materials whose rheological and mechanical properties can be modified by an external magnetic field. These materials are used in technologies to build adaptive devices and effectively suppress vibrations in various mechanical systems. The paper overviews advances in MR fluid properties and their application in broader literature, focusing on flow, yield strength, and viscoelastic behavior under shearing flows.

Suryawanshi Ravishankar.et.al. [14] This paper provides an in-depth study of Magnetorheological fluids (MRFs) and their tunable properties. The research discusses the characteristics, composition, and working principles of MR fluids, including their applications in various engineering sectors. The goal is to offer readers a basic understanding of MR fluid technology and components.

Anna Fenyk.et.al. [15] This paper presents the results of studies on eight magnetorheological (MR) fluids with different compositions. The authors used magnetite and carbonyl iron as magnetic particles and tested MR fluids with glycerin and OKS 352 oil, stabilizers like oleic acid and Aerosol 200 silica, and additives such as graphite and yellow dextrin. The study aims to assess the impact of various component combinations on the dynamic properties of MR fluids, including structural yield stress and flow stress at varying magnetic field induction values.

Jiří Žáček.et.al. [16] This paper explores the gradient pinch mode of Magnetorheological (MR) fluids, a less-explored operating mode where non-uniform magnetic field distributions create a Venturi-like contraction in MR fluids. This allows for unique variations in pressure-flow rate characteristics and solidifies the material near the flow channel walls, creating a passage for fluid to pass through. The study suggests that further investigation is needed into the effect of MR fluid composition on its behavior in this mode.

Osama Ashour.et.al. [17] This paper investigates the use of Magnetorheological (MR) fluids in hydraulic systems, actuators, valves, and vibration dampers. MR fluids, which consist of stable suspensions of magnetic particles in a carrier fluid, have the potential to revolutionize the design of active shock and vibration damping systems. The study emphasizes the need for improved MR fluids, cost-effective manufacturing processes, and application devices that demonstrate their engineering feasibility.

3. Problem Identification

Magnetorheological (MR) fluids are smart materials whose rheological properties can be rapidly and reversibly altered by the application of a magnetic field. These fluids typically consist of micrometer-sized magnetic particles suspended in a carrier liquid. However, one of the critical challenges in the practical application of MR fluids is the sedimentation of magnetic particles due to their high density relative to the carrier fluid. This sedimentation leads to instability, non-uniform particle distribution, and degradation of the fluid's performance over time.

Understanding and controlling the sedimentation behaviour is essential for improving the long-term stability and functionality of MR fluids in applications such as dampers, clutches, prosthetics, and robotics. Additionally, investigating the action of MR fluids under different magnetic field strengths can provide insights into how field-induced structure formation affects both sedimentation and fluid dynamics.

This study aims to analyse the sedimentation rate of MR fluids under varying conditions (such as magnetic field strength, particle concentration, and carrier fluid viscosity) and to examine the mechanisms by which the applied magnetic field influences particle alignment, agglomeration, and overall rheological behaviour.

4. Objectives

The main objectives of this MR fluid analysis are

- To synthesize stable MR fluid samples using appropriate carrier fluids, surfactants, and magnetic particles (e.g., carbonyl iron particles), ensuring proper dispersion and minimal agglomeration.
- To investigate the influence of magnetic field strength on the rheological properties of the MR fluid, including changes in viscosity, yield stress, and particle chain formation.
- To analyse the effect of particle concentration and distribution on the overall stability and performance of MR fluids under varying environmental and operational conditions.

5. Methodology

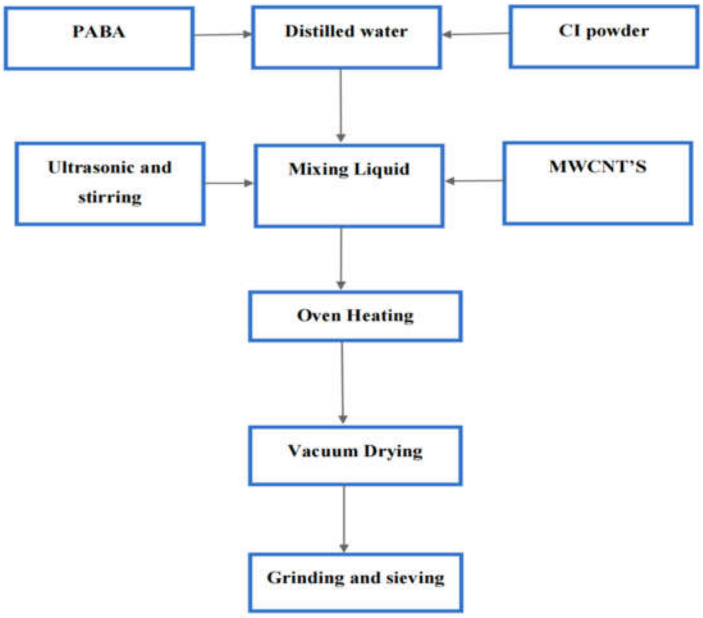

Figure 1: Flow chart of coating CI particles to MWCNTs

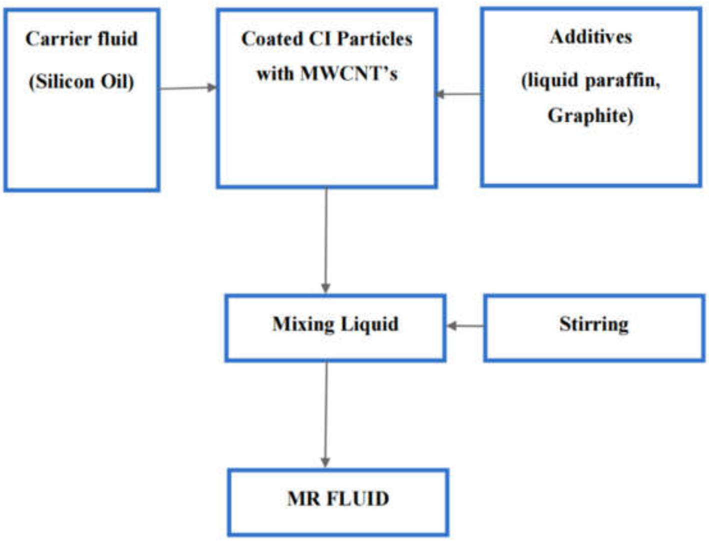

Figure 2: Flow chart of MR fluid preparation

6. Selection of Materials

- Carbonyl powder (99% Purity)

  The term carbonyl powder can refer to a few different materials, primarily metal carbonyls such as iron carbonyl ($Fe(CO)_5$) or nickel carbonyl ($Ni(CO)_4$).

- Silicon oil

  Silicon Oil is a type of synthetic oil that is composed of a polydimethylsiloxane (PDMS) polymer, which is a type of silicone compound.

- Para-amino benzoic acid (PABA)

  Para-amino benzoic acid (PABA), also known as 4-aminobenzoic acid, is an organic compound that belongs to the aromatic amine family.

- MWCNT's (multi-walled carbon nano tubes)

  Multi-walled carbon nanotubes (MWCNTs) are cylindrical structures made of multiple layers of graphene sheets, which are a single layer of carbon atoms arranged in a hexagonal lattice.

- Liquid paraffin

  Liquid paraffin, also known as mineral oil, is a clear, colorless, odorless, and tasteless hydrocarbon that is derived from petroleum.

- Graphite

  Graphite fine powder is a finely ground form of graphite, a naturally occurring allotrope of carbon. Graphite consists of layers of carbon atoms arranged in a hexagonal lattice, and it is one of the most widely used materials due to its excellent conductivity, lubricating properties, and thermal stability

7. Quarter car model

The Quarter Car Model is a simplified representation used in vehicle dynamics to study how a car responds to road irregularities. As the name suggests, it represents one-fourth of the vehicle—typically modelling a single wheel and the portion of the vehicle body supported by that wheel. This simplification makes it easier to analyse and design suspension systems without the complexity of a full vehicle model.

The model generally consists of two masses: the sprung mass, which represents the portion of the vehicle body supported by the suspension (like the chassis), and the unsprung mass, which includes components like the wheel, tire, and a small part of the suspension itself. These masses are connected by a spring and a damper (shock absorber), which simulate the car's suspension system. The tire is usually modelled as a spring connected to the road surface.

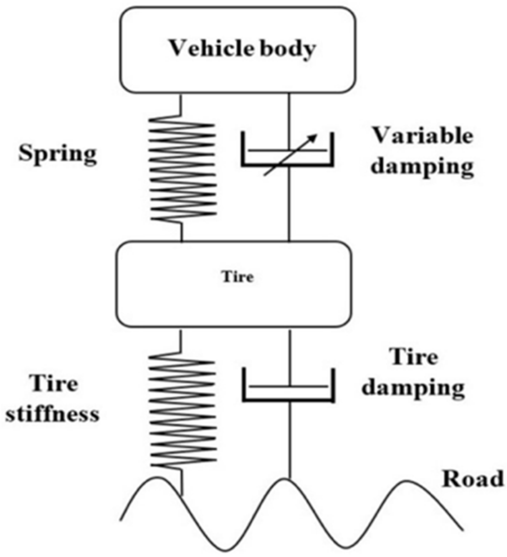

Figure 7: System on the different road

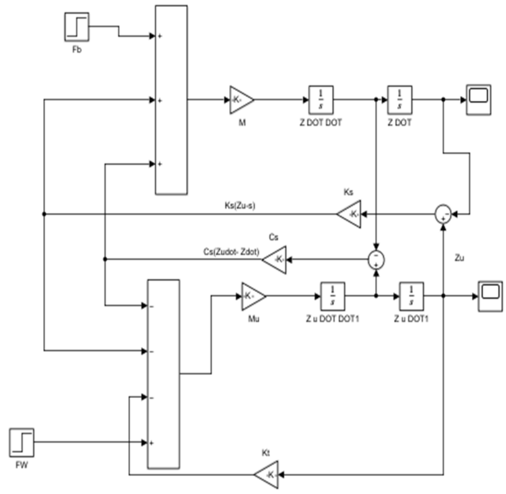

Figure 8: Quarter car model

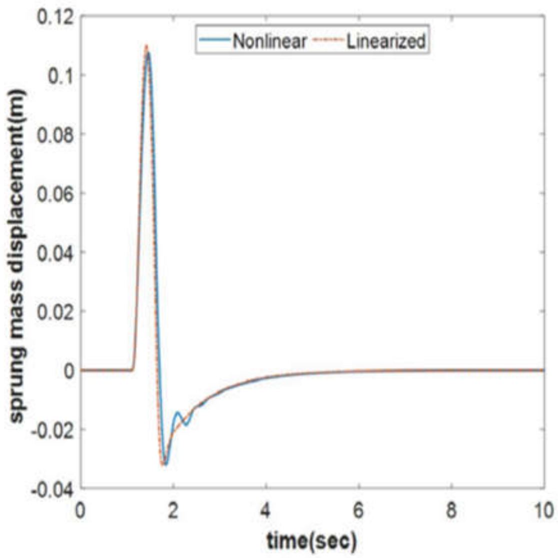

Figure 9: Response of Quarter Car Model

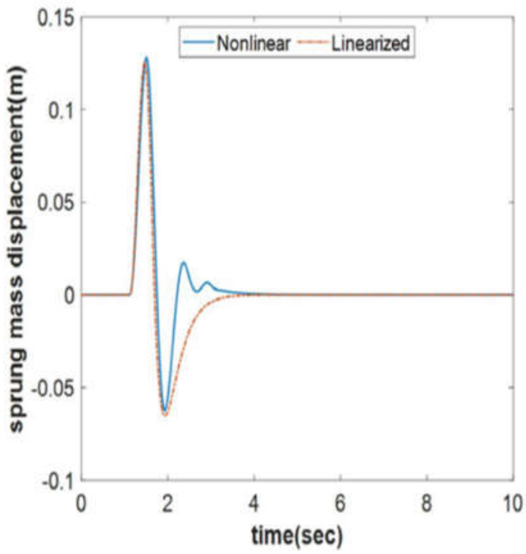

Figure 10: Response of Quarter Car Model

8. Result and disscussion

The Research of MR fluid determines

- Figure 3 explains the decrease in the value of shear stress as the shear rate is constant. Analyzing this plot allows you to determine the transition from solid-like to fluid-like Behavior.
- Figure 4 explains that as the magnetic field strength increases the yield strength will also increase. This plot is crucial in determining the tunability of the MR fluid.
- Figure 5 graph explains the viscosity decreases in constant shear rate. Characterizing the rheological Behavior in this way is important for understanding how the MR fluid performs under rapid motion

or flow.

- When we talk about figure 6 it gradually increasing at a very small rate and at certain times it becomes stable. Good performance means the fluid maintains its homogeneity for a reasonable period, although some settling may occur eventually.

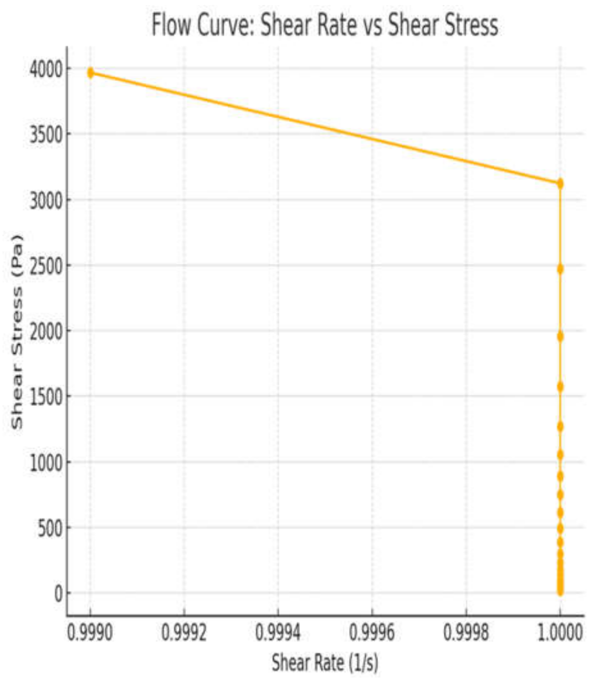

Figure 3: Shear Rate vs Shear Stress

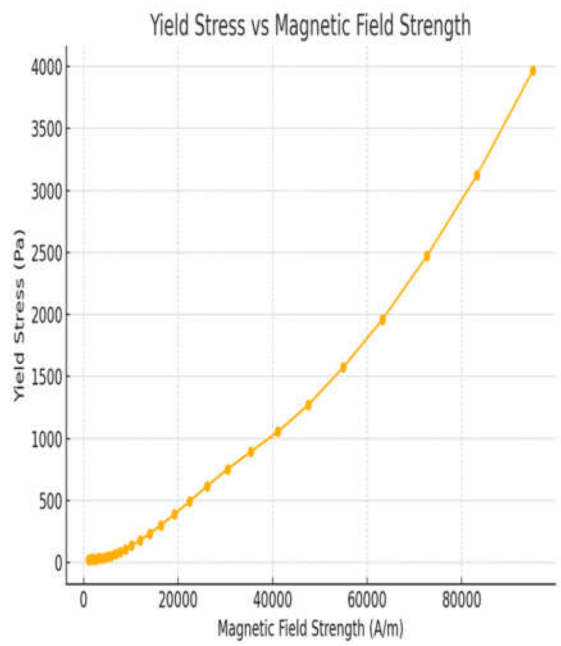

Figure 4: Magnetic Field Strength vs Yield Stress

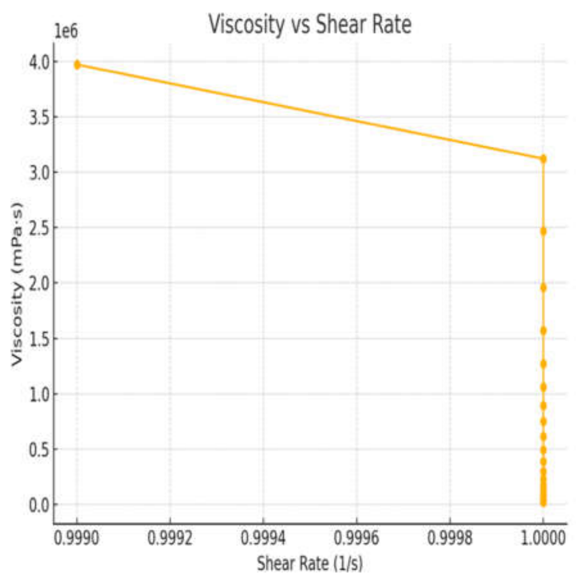

Figure 5: Shear Rate vs Viscosity

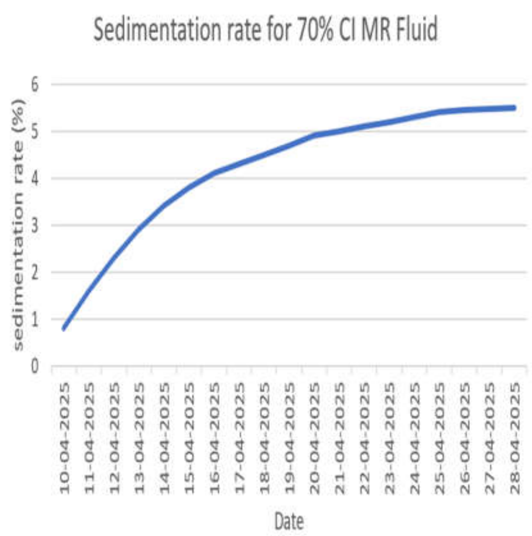

Figure 6: Time vs Sedimentation rate (%)

9. Conclusion

MR fluids represent a breakthrough in smart material technology, offering rapid and reversible viscosity changes in response to magnetic fields.

The use of grafting technology, particularly MWCNT coating, has significantly enhanced the performance of MR fluids by improving their sedimentation stability while maintaining adequate magnetic properties.

The research proves further advancements in coating methods and fluid formulations will continue to enhance the efficiency and durability of MR fluids, expanding their applicability across various engineering fields.

The magnetorheological (MR) fluids prepared with varying percentages of carbonyl iron powder exhibited distinct rheological behaviors under different road conditions. As the CIP concentration increased, the yield stress and damping force also increased, enhancing the fluid's ability to adapt to dynamic environments. MR fluid with 55%, 60%, 65%, 70% of CIP demonstrated the best balance between responsiveness and stability, making it the most suitable for a wide range of road conditions including smooth, rough, and uneven terrains. These findings confirm that tuning the CIP concentration allows for effective control of suspension systems in real-time, improving vehicle comfort and safety.

10. References

[1] Thomas Leps and Christine Hartzell, Element Method Simulation of Magnetorheological Fluids Using Accurate Particle Size Distributions in LIGGGHTS Extended with Mutual Dipole Method, 2021.

[2] Pranav Gadekar, V.S. Kanthale, and N.D. Khaire, Magnetorheological Fluid and its Applications, 2017.

[3] High-Fidelity, Discrete Fidelity Simulation of Magnetorheological (MR) Fluids Using the Discrete Element Method (DEM), [No author given].

[4] Ashish Gupta and Vikas Rastogi, Effects of Various Road Conditions on Dynamic Behaviour of Heavy Road Vehicle, 2016.

[5] Fu Li, Guan Wei, Wang Qi, and Xu Xinhe, Modelling and Adaptive Control of Magneto-Rheological Buffer System for Aircraft Landing Gear, 2014.

[6] Wu Dong-su, Gu Hong-bin, and Liu Hui, GA-Based Model Predictive Control of Semi-Active Landing Gear, 2007.

[7] Fan Ran, Fang Yuanyuan, Han Yu, Xue Caijun, and Wang Enzhen, Landing Dynamic Simulation of Aircraft Landing Gear with Multi-Struts, 2014.

[8] Dr. T. Haritha, Hemanth, D. Rajesh, and B.R.V. Satyanarayana, Design and Analysis of Aircraft Landing Gear, 2014.

[9] Divakaran VN, Dr. Ravikumar G., and VV Srinivasa Rao Patnala, Aircraft Landing Gear Design & Development, 2018.

[10] A. Toloei, E. Aghamirbaha, and M. Zarchi, Mathematical Model and Vibration Analysis of Aircraft with Active Landing Gear System Using Linear Quadratic Regulator Technique, 2016.

[11] Şahin Yıldırım and Aslı Durmuşoğlu, Vibration Analysis and Control of Aircraft Landing Systems Using Proposed Neural Controllers, 2024.

[12] TA Instruments, Rheological Techniques for Yield Stress Analysis, July 2024.

[13] Magdalena Osial, Agnieszka Pregowska, Magdalena Warczak, and Michael Giersig, Magnetorheological Fluids: A Concise Review of Composition, Physicochemical Properties, and Models, 2023.

[14] Suryawanshi Ravishankar and Rayappa Mahale, A Study on Magneto Rheological Fluids and Their Applications, 2015.

[15] Anna Fenyk, Wojciech Horak, and Marek Zieliński, Investigation of the Effect of MR Fluid Composition on Properties at Low Strain Ranges, 2023.

[16] Jiří Žáček, Zbyněk Strecker, Filip Jeniš, Ondřej Macháček, Janusz Goldasz, Bogdan Sapinski, Martin Vrbka, and Michal Kubík, Impact of Magnetorheological Fluid Composition on Their Behaviour, 2024.

[17] Osama Ashour, Craig A. Rogers, and William Kordonsky, Magnetorheological Fluids: Materials, Characterization, and Devices, 2013.