ISSN : 2455-9679
SJIF Impact Factor : 6.190

IJRTSM
INTERNATIONAL JOURNAL OF RECENT TECHNOLOGY SCIENCE & MANAGEMENT

"MAGNETO-RHEOLOGICAL FLUID DAMPERS FOR MOTORCYCLE FRONT SUSPENSION: A REVIEW OF FLUIDS, DAMPER DESIGN, MODELLING AND CONTROL"

Rajkumar Jat [1], Dr Amit Bahekar [2]

[1] PG scholar, Department of Mechanical Engineering, SAGE University, Indore, Madhya Pradesh, India
[2] Associate Professor, Department of Mechanical Engineering, SAGE University, Indore, Madhya Pradesh, India

ABSTRACT

A motorcycle front fork has to balance rider comfort against handling over a wide range of road excitation, but the conventional telescopic fork uses fixed-orifice passive damping that cannot adapt to the road. Magneto-rheological (MR) fluid dampers are a semi-active alternative: the damping force is changed quickly by the current in a small coil, the power demand is low, and the damper remains passive if the control fails. This paper reviews published studies on MR technology that bear on two-wheeler front suspension. It covers MR fluid formulation and sedimentation, damper configurations and magnetic-circuit design, hysteresis and flow models, semi-active control and sensing, and experimental characterisation. The review shows that most work concerns automotive, civil and industrial dampers, while compact fork-scale dampers, low-cost laboratory-prepared fluids, and matched field and force data are reported far less often. The gaps identified point to a clear programme for fork-scale MR damper research.

Key Words: *Magneto-rheological fluid; MR damper; semi-active suspension; motorcycle front fork; vibration control; damper modelling.*

I. INTRODUCTION

Suspension design for motorcycles has always been a compromise. The first machines had no suspension; a sprung seat came first, then a sliding fork with springs, which was more comfortable but kept oscillating because it had no damping. Adding a damper produced the telescopic fork, which houses spring and damper in one light and inexpensive unit and is still the dominant front suspension [1]. The damping, however, remains passive and is set before the ride.
A damper tuned for comfort is soft in braking and cornering, while one tuned for handling transmits road shock. Fully active suspension removes the compromise but costs more and needs power. Semi-active suspension, first formalised by Karnopp et al. [2], changes the damping of an element in real time without adding energy to the vibrating system [3]. MR fluids are the most widely studied smart fluids for this purpose: a suspension of magnetisable particles in oil flows freely without a field and becomes semi-solid within a field, and the change is reversible [4], [5].

II. PROBLEM IDENTIFICATION

MR dampers are used in production cars, structures, presses and prosthetics, but published work on motorcycle front forks is limited. A fork leg needs a small cylinder, a short stroke and a low-cost fluid, whereas most reported dampers are larger units with factory-made fluids. The effect of the particle type, the stabiliser, the coil current and the exciter conditions on a fork-scale damper is therefore hard to find in one place. A structured review of fluids, damper design, models and control is needed to see what is already established and what is missing for two-wheelers.

ISSN : 2455-9679
SJIF Impact Factor : 6.190

III. Research Objective

The main objectives of the present review are as follows:

- To summarise MR fluid composition, the MR effect, sedimentation and operating modes.
- To compare damper configurations, magnetic-circuit design and optimisation methods.
- To review hysteresis and flow models, semi-active control strategies, sensing and test methods.
- To identify research gaps for fork-scale MR dampers on motorcycles.

IV. Magneto-Rheological Fluids

4.1 Composition

An MR fluid has three components: a carrier fluid, magnetisable particles and additives [1], [4]. The carrier supports the particles and supplies damping when the field is off, so its viscosity should be low and nearly independent of temperature. Mineral oil, synthetic oil, silicone oil, water and glycol are used; silicone oil offers good thermal stability and a very wide usable range (about −40 to 204 °C) but is difficult to seal [1]. The particles are iron or iron oxides, typically spherical and 1 to 50 µm across, with volume fractions up to about fifty per cent; larger particles raise the attainable force and also the off-state viscosity [1]. Additives such as grease, ferrous naphthenate or oleate and lithium stearate slow settling and keep the particles apart, and polymer coatings reduce their effective density [1]. Table 4.1 lists typical constituents.

Table 4.1: Typical constituents of MR fluids

Constituent	Typical choices	Role
Carrier oil	Mineral, synthetic or silicone oil; water; glycol	Supports particles; off-state viscosity
Particles	Iron, carbonyl iron, Fe_2O_3, Fe_3O_4 (1–50 µm)	Form chains in the field
Additives	Grease, ferrous naphthenate or oleate, lithium stearate, coatings	Reduce settling; keep particles apart

4.2 MR effect and sedimentation

In a field each particle becomes a dipole, the dipoles attract, and chains form along the flux lines; the fluid then behaves like a Bingham plastic with a yield stress that must be exceeded before flow starts [4], [5]. The effect is large, reversible and fast, and MR fluids are comparatively insensitive to moisture and contaminants [5]. The main practical weakness is sedimentation: the particles are much denser than the carrier and settle, and surfactants that reduce settling also reduce magnetic saturation and so the maximum yield stress [1].

4.3 Operating modes

MR devices use flow (valve), shear or squeeze mode, with the field perpendicular to the plates. Dampers use flow mode, with fluid pushed through a fixed gap; clutches and brakes use shear mode; squeeze mode gives high forces at small amplitudes [4]. A fork damper normally operates in flow mode, with the fluid passing through annular or grooved paths in the piston.

ISSN : 2455-9679
SJIF Impact Factor : 6.190

V. Damper Design And Modelling

5.1 Configurations and magnetic circuit

Three layouts dominate. A mono-tube damper has one reservoir and an accumulator to take up the volume change; a twin-tube damper has inner and outer reservoirs; a double-ended damper has a rod on both sides and needs no accumulator [1]. The coil is wound on the piston, and flux crosses the fluid gap, typically 0.5 to 2 mm, perpendicular to the flow, returning through the outer cylinder. Core and flux return are made of high-permeability steel, and the casing of aluminium alloy [1].

Several authors treat design as optimisation. Patil et al. [6] derived equations for the gap volume, thickness and width from the required force and piston speed. Tu et al. [7] combined magnetic circuit, accumulator and structure in one design, analysed the circuit by finite elements and derived the damping-force formula. Parlak et al. [8] used ANSYS electromagnetic and CFD tools to optimise geometry, current and yield stress for a target force of 1000 N.

5.2 Modelling

Quasi-static models based on the Bingham plastic give force from geometry and yield stress; Çeşmeci and Engin [9] showed that a flow model captured the dynamic force range of a fabricated damper tested on a shock machine. Chooi and Oyadiji [10] obtained analytical solutions for annular flow, found that the plug region shrinks as flow increases, and validated them by CFD. Parlak and Engin [11] combined quasi-static analysis with transient CFD using deformed meshes. Parametric hysteresis models describe force against velocity: Ambhore et al. [12] compared modified and simple Bouc-Wen models, Yao et al. [13] used a Bouc-Wen model in a quarter-car study, and Yang et al. [14] fitted a polynomial hysteretic model whose parameters depend on current. Wang and Liao [15] review these models in detail. Table 5.1 compares representative studies.

Table 5.1: Representative design and modelling studies

Ref.	Focus	Method	Principal finding
[12]	Hysteresis	Modified vs simple Bouc-Wen	Modified model predicts force-velocity better
[14]	Hysteresis	Polynomial fits of parameters vs current	Close match with test data
[7]	Design	Magnetic-circuit FEM, accumulator damper	Force formula derived; tested
[9]	Modelling	Bingham flow model, shock machine	Flow model captures force range
[11]	CFD	Quasi-static and transient CFD	Plug thickness and force predicted
[6]	Design	Geometric design equations	Gap dimensions from required force
[8]	Optimisation	ANSYS FEM and CFD, 1000 N target	Optimum geometry and current found
[10]	Flow solution	Analytical annular flow, CFD check	Plug region shrinks as flow increases

VI. Control, Sensing And Research Gaps

6.1 Control strategies

Hudha et al. [16] evaluated skyhook, groundhook and hybrid controllers for a semi-active MR damper, judging them by disturbance rejection and by how well the damper could produce the demanded force. Karimi [17] proposed backstepping and heuristic controllers for MR-damped suspensions, and Pozo et al. [18] found that a variable-structure controller with an updating term performed best among three and was more robust than the passive device. Milecki [19] analysed control of controllable fluid dampers and noted the cost and complexity of active alternatives.

ISSN : 2455-9679
SJIF Impact Factor : 6.190

6.2 Sensing, response and testing

Lam et al. [20] integrated a piezoelectric force sensor and an LVDT into an MR damper for self-sensing. On motorcycles, low-cost accelerometers pick up large amounts of engine vibration, so an absolute position encoder is a more accurate option [1]. Koo et al. [21] proposed a method for the response time of MR dampers and showed that it depends on current, piston velocity and system compliance. Liao and Lai [22] quantified energy dissipation under harmonic excitation and compared it with a viscous damper, and Ahmadian and Norris [23] tested two configurations under impact loads. Applications include construction vehicles, structures, presses [24] and production cars [1].

6.3 Research gaps

- **Scale.** Compact units with a cylinder of about 30 mm and a stroke of about ±25 mm, as needed in a fork leg, are rarely reported.
- **Fluid formulation.** Full recipes and comparisons of particle type or additive level are scarce, and sedimentation is described only qualitatively.
- **Field and force data.** Studies give either damper force or the field in the gap; matched sets of current, field, displacement and force are needed.
- **Control under noisy sensing.** Engine vibration in accelerometer signals on motorcycles has not been addressed in the controllers reviewed.
- **Durability and road tests.** Seal life, heating and long-term settling are little reported, and on-road tests on a motorcycle are largely absent.

VII. CONCLUSION

MR fluid dampers offer a semi-active, low-power, fail-safe way to remove the comfort-handling compromise of a passive motorcycle fork. Mature tools exist for the fluid, the damper geometry, the model and the controller, including Bingham, Bouc-Wen and CFD models, finite-element magnetic design, and skyhook-type or nonlinear control. The literature concentrates on larger systems, however. Future work on motorcycle forks should supply complete fluid recipes and field data, fork-scale dampers with matched force and displacement measurements, controllers robust to engine vibration, and durability and on-road tests.

REFERENCES

[1] T. B. Nema, “Experimental analysis of magneto-rheological fluid based front fork tally lever suspension,” M.Tech. dissertation, Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal, India, 2026.
[2] D. Karnopp, M. J. Crosby, and R. A. Harwood, “Vibration control using semi-active force generators,” *Journal of Engineering for Industry*, vol. 96, no. 2, pp. 619–626, 2021.
[3] N. Sims, R. Stanway, and A. Johnson, “Vibration control using smart fluids: a state-of-the-art review,” *Shock and Vibration Digest*, vol. 31, no. 3, pp. 195–203, 2022.
[4] A. G. Olabi and A. Grunwald, “Design and application of magneto-rheological fluid,” *Materials & Design*, vol. 28, pp. 2658–2664, 2024.
[5] M. R. Jolly, J. W. Bender, and J. D. Carlson, “Properties and applications of commercial magnetorheological fluids,” *Journal of Intelligent Material Systems and Structures*, vol. 10, no. 1, pp. 5–13, 2025.
[6] M. A. Patil, S. Sapkale, and S. Soni, “Theoretical and experimental research on magneto-rheological damper with DC input,” *International Journal of Mechanical Engineering and Technology*, vol. 3, no. 2, pp. 610–619, 2022.
[7] F. Tu, Q. Yang, C. He, and L. Wang, “Experimental study and design on automobile suspension made of magneto-rheological damper,” *Energy Procedia*, vol. 16, pp. 417–425, 2023.
[8] Z. Parlak, T. Engin, and İ. Çalli, “Optimal design of MR damper via finite element analyses of fluid dynamic and magnetic field,” *Mechatronics*, vol. 22, pp. 890–903, 2024.

ISSN : 2455-9679
SJIF Impact Factor : 6.190

[9] Ş. Çeşmeci and T. Engin, "Modeling and testing of a field-controllable magnetorheological fluid damper," *International Journal of Mechanical Sciences*, vol. 52, pp. 1036–1046, 2020.
[10] W. W. Chooi and S. O. Oyadiji, "Design, modelling and testing of magnetorheological dampers using analytical flow solutions," *Computers & Structures*, vol. 86, pp. 473–482, 2021.
[11] Z. Parlak and T. Engin, "Time-dependent CFD and quasi-static analysis of magnetorheological fluid dampers with experimental validation," *International Journal of Mechanical Sciences*, vol. 64, pp. 22–31, 2022.
[12] N. Ambhore, S. Hivarale, and D. R. Pangavhane, "A study of Bouc-Wen model of magneto-rheological fluid damper for vibration control," *International Journal of Engineering Research & Technology*, vol. 2, no. 2, 2023.
[13] G. Z. Yao, F. F. Yap, G. Chen, W. H. Li, and S. H. Yeo, "MR damper and its application for semi-active control of vehicle suspension system," *Mechatronics*, vol. 12, pp. 963–973, 2024.