Preface

By definition, solids and fluids have been characterized with different physical laws. The behaviour of linear solids, for instance, can be quantified using Hooke's law of elasticity, and the rheology of linear fluids can be governed by Newton's viscosity law. Some materials, however, do not fit into the principal definition. Examples of such materials are magnetorheological/electrorheological (MR/ER) fluids well known under the name of smart fluids. The materials undergo major physical changes upon the application of an external (magnetic or electrical) stimulus so that they can be converted from a fluid to a pseudo-solid material. The reversible nature of the phenomena, the dramatic magnitude of changes and the speed of response have made them suitable for use in vibration isolation and control. The characteristics have been found useful in engineering systems where real-time performance, which follows changing conditions of system operation, is required.

No more than a scientific curiosity for decades since their discovery in the 1940s, both have deceived and tempted researchers and scientists for years. Till the early 1990s, the majority of research efforts concentrated on ER fluids; their limitations, electrical and safety issues, however, rendered them unsuitable for real-life applications at that time. MR fluids promptly stepped in, and once technological and control issues were overcome, the material was successfully utilized by the automotive industry in a valveless controlled chassis system application in passenger vehicle in the North American market in 2002. The system used MR fluid-based shock absorbers otherwise known as MR vehicle dampers. Since that time and as of 2012, the system marketed under the name of MagneRide has been put to a regular use in many passenger vehicle models as a standard suspension system or in the form of an option. A commercial application of a semi-active MR powertrain mount in a 2009 high performance passenger car completes the list.

Recently, one aspect of MR damper applications that has received a great deal of researcher's attention is energy harvesting. Here, in a typical configuration an MR device is driven by energy harvested from a vehicle while in motion. The mechanical energy that otherwise would be unused and lost through heat is converted into electricity and used for monitoring the output of an associated MR device. This trend is accompanied by the industry's interest in hybrid and electrical vehicles. Vehicle suspension applications of energy harvesting dampers seem immediate; however, factors including the recovered energy magnitude, manufacturability, lifecycle, weight and cost may prevent such applications from commercialization in real-life.

Briefly, an automotive MR damper when used within a controlled environment, and in a vehicle suspension in particular, has its piston rod driven by a prescribed displacement/force. At the same time, the damper's coil is supplied with a current signal. The coil is located in the piston assembly of the damper. The commanded current is supplied to the coil through a pulse-width-modulated (PWM) driver. The current in the coil induces a magnetic field in the actuator in order to modify the MR fluid's yield stress and the damping force at the same time. The changes in the magnetic field passing through the components in the magnetic circuit of the actuator induce an electromotive force, whilst eddy currents are generated in the actuator's core. Furthermore, the eddy currents produce a magnetic field opposing the flux changes, and the speed of response of MR dampers becomes slower. Therefore, capturing the time-varying behaviour of the MR damper with the PWM current driver supplying the commanded current to the coil is necessary for describing the characteristics of an MR device. It involves a detailed description of the coil's resistance to the change of current and coupling among the magnetic field-induced yield stress and the damping force output (hydraulic circuit), as well as the dynamics of current drivers used for controlling the output of MR dampers.

In brief, the main objective of this book is to provide the readers with information on theoretical and practical aspects of MR damper operation, modelling and engineering. By definition, the word *insight* that is contained in the title of the book can describe a piece of information, an understanding of cause and effect based on identification of relationships and behaviours within a model or an instance of apprehending the true nature of a thing. By itself, it makes a promise to the potential readers and imposes obligations on the authors, and by following its spirit the authors hoped to provide the necessary foundations for the information in the book either in the form of theoretical knowledge or applied solutions. Specifically, the book contains the background information on smart fluids and related devices, common configurations as well as theory and its experimental verification. Following a review of the technology, theoretical backgrounds are provided of MR fluid compositions and key factors affecting the characteristics of these fluids is followed by a description of existing configurations of dampers and control valves. Specifically, the authors highlight common configurations of flow-mode MR dampers that have been considered by the automotive industry for controlled chassis applications. The authors focus on single-tube dampers utilizing a piston assembly with one coil or multiple coils and at least one annular flow channel in the piston.

Clearly, for modelling and design of a math-based analytical model of an exemplary MR fluid device, a flow-mode monotube damper is needed. Within the automotive industry it is a common practice to exercise entry-level scenarios with steady-state models, whereas more in-depth tests incorporating non-stationary and fluctuating magnetic fields are usually performed by means of more advanced tools capable of copying the devices' dynamic features of interest. Here, the author's attention has been focused on models suitable for steady-state design analyses as well as dynamic studies, respectively. The task has been always somewhat of a challenge as with MR fluids the ability to model and quantify the behaviour of a material that is multidisciplinary by nature has always been a daunting exercise. It requires the knowledge of the material's rheology, electrical and mechanical engineering as well as control theory principles. First, a review of several constitutive models of non-Newtonian fluids in planar flow is carried out, and a novel exact (analytical) solution for them in terms of several non-dimensional parameters is obtained and analysed. The parameters capture the effects of plasticity, inertia, viscosity, shear thinning/thickening, and they allow for expressing the behaviour of an MR damper in pre-yield as well as post-yield flow regimes in a manner that is easy to follow and comprehend. Their application is highlighted in a fairly realistic steady-state model of a flow-mode MR damper configuration incorporating primary and secondary flow channels of MR fluid. A dynamic model of the damper for use in component-level as well as vehicle-level studies is also followed. In addition to copying the device's characteristics associated with the yield stress, the model also incorporates the effects of fluid compressibility, inertia, flow leakage past MR piston, friction, floating piston inertia, cavitation, gas pressure and the like. Furthermore, for the purpose of testing and verification, both models were applied to experimental data of several fabricated MR damper prototypes of a customized piston design and successfully verified across a wide range of piston velocity inputs, displacement amplitudes and coil current levels.

To summarize, Chap. 1 is an introduction to the material included in the book, whereas Chap. 2 includes a review of MR fluid formulations and key components affecting the fluids' performance in a semi-active environment. The information is followed in Chap. 3 by a thorough review of fundamental configurations of automotive flow-mode dampers. Next, in Chap. 4 the authors provide the reader with an application of several key non-Newtonian fluid models while in the MR damper environment. Chapter 5 contains a review of lumped parameter models of MR single-tube and double-tube dampers, respectively. Chapter 6 contains complementary information on MR fluid flow modelling using numerical Computational Fluid Dynamics (CFD) methods, whereas Chap. 7 reveals power driver structures for MR devices as well as control circuits and exemplary control strategies. In Chap. 8 the authors present results of several experiments involving customized prototypes of automotive flow-mode MR dampers. Finally, Chap. 9 highlights the development of energy harvesting MR dampers and Chap. 10 is a summary.

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