17

Semi-active Control

17.1 Introduction

Active control systems rely entirely on external power to operate the actuators and supply the control forces. In many applications, such systems require a large power source, which makes them costly (this is why there has been very few cars equipped with fully active suspensions) and vulnerable to power failure (this is why the civil engineering community is reluctant to use active control devices for earthquake protection). Semi-active devices require a lot less energy than active devices; and the energy can often be stored locally, in a battery, thus rendering the semi-active device independent of any external power supply. Another critical issue with active control is the stability robustness with respect to sensor failure; this problem is especially difficult when centralized controllers are used.

On the contrary, semi-active control devices are essentially passive devices where properties (stiffness, damping,...) can be adjusted in real time, but they cannot input energy directly in the system being controlled. Note however that since semi-active devices behave non-linearly; they can transfer energy from one frequency to another. The variable resistance law can be achieved in a wide variety of forms, as for example position controlled valves, rheological fluids, or piezoelectrically actuated friction joints.

Over the past few years, semi-active control has found its way in many vibration control applications, for large and medium amplitudes, (particularly vehicle suspension, but also earthquake protection,...). However, it should be kept in mind that, in most cases, semi-active devices are designed to operate in the “post yield” region, when the stress exceeds some controllable threshold; this makes them inappropriate for vibrations of small amplitude where the stress remains below the minimum controllable threshold in the device. It should also be pointed out that, in many applications (e.g. domestic appliances), the cost of the control system is a critical issue (it is much more important than the optimality of the performances); this often leads to simplified control architectures with extremely simple sensing devices.
Magneto-rheological fluids exhibit very fast switching (of the order of millisecond) with a substantial yield strength; this makes them excellent contenders for semi-active devices, particularly for small and medium-size devices, and justifies their extensive discussion. This chapter begins with a review of magneto-rheological (MR) fluids and a brief overview of their applications to date. Next, some semi-active control strategies are discussed.

17.2 Magneto-Rheological Fluids

In 1947, W.Winslow observed a large rheological effect (apparent change of viscosity) induced by the application of an electric field to colloidal fluids (insulating oil) containing micron-sized particles; such fluids are called electro-rheological (ER) fluids. The discovery of MR fluid was made in 1951 by J.Rabinow, who observed similar rheological effects by application of a magnetic field to a fluid containing magnetizable particles. In both cases, the particles create columnar structures parallel to the applied field (Fig.17.1) and these chain-like structures restrict the flow of the fluid, requiring a minimum shear stress for the flow to be initiated. This phenomenon is reversible, very fast (response time of the order of milliseconds) and consumes very little energy. When no field is applied, the rheological fluids exhibit a Newtonian behavior.

Typical values of the maximum achievable yield strength $\tau$ are given in Table 17.1. ER fluids performances are generally limited by the electric field breakdown strength of the fluid while MR fluids performances are limited by the magnetic saturation of the particles. Iron particles have the highest saturation magnetization. In Table 17.1, we note that the yield stress of MR fluids is 20 to 50 times larger than that of ER fluids. This justifies why most practical applications use MR fluids. Typical particle sizes are 0.1 to 10μm and typical particle volume fractions are between 0.1 and 0.5; the carrier fluids are selected on the basis of their tribology properties and thermal stability.

![Fig. 17.1 Chain-like structure formation under the applied external field.](image-url)