CHAPTER 4

MR DAMPER DESIGN

In this chapter, details of MR damper geometry and magnetic circuit design are provided. Additional practical considerations for MR damper design, such as damper piston centering and voltage surge suppression, are also discussed. Problem resolutions are given.

4.1 MR Damper Geometry Design

For the MR damper geometry design, assume that the following parameters are given:
(1) MR fluid yield stress \( \tau_0 \), and fluid parameters \( K \) and \( m \).
(2) MR damper size \( R_2 \).
(3) Maximum allowable velocity \( v_0 \) of the MR damper.

The geometry design task is to choose an appropriate gap size \( h \) and active pole length \( L \) such that the design requirements of dynamic range \( D \) and controllable force \( F_{\tau} \), are achieved.

As shown in Eq. (3.60), the dynamic range \( D \) is given by

\[
D = \frac{F}{F_{uc}} = \frac{F_{\tau} + F_{\eta} + F_f}{F_{\eta} + F_f} \tag{4.1}
\]

where \( F \) = damper resisting force which includes a controllable force \( F_{\tau} \) due to controllable yield stress \( \tau_0 \), a plastic viscous force \( F_{\eta} \), and a friction force \( F_f \); and \( F_{uc} \) = uncon-
trollable force which includes a viscous force $F_\eta$ and a friction force $F_f$. It is impossible to know the exact value of the friction force before the damper is built and tested. However, one can reasonably assume that $F_\eta = F_f$ (Engineering Note 1999a). Moreover, because $F_\tau + F_\eta \gg F_f$, Eq. (4.1) can be written as

$$D = \frac{F_\tau + F_\eta}{2F_\eta}$$  \hspace{1cm} (4.2)

Because $F_\tau + F_\eta = (dp/dx)_{\tau_0} A_p L$ and $F_\eta = (dp/dx)_{\tau_0 = 0} A_p L$ where $A_p$ = piston cross section area; $L$ = active pole length; $(dp/dx)_{\tau_0}$ = pressure gradient with fluid yield stress; and $(dp/dx)_{\tau_0 = 0}$ = pressure gradient without fluid yield stress, Eq. (4.2) can be further manipulated as

$$\frac{(dp/dx)_{\tau_0}}{(dp/dx)_{\tau_0 = 0}} = 2D$$ \hspace{1cm} (4.3)

Using Eqs. (3.16)–(3.19) and (3.23)–(3.25), a gap size $h$ can be determined such that

$$\frac{(dp/dx)_{\tau_0}}{(dp/dx)_{\tau_0 = 0}} \geq 2D$$ \hspace{1cm} (4.4)

Note that the gap needs to be chosen to have a reasonable size without causing manufacture difficulties. The active pole length $L$ can then be calculated with the equation

$$L = \frac{F_\tau}{A_p[(dp/dx)_{\tau_0} - (dp/dx)_{\tau_0 = 0}]}$$ \hspace{1cm} (4.5)

and the damper resisting force $F$ can be estimated by

$$F = (dp/dx)_{\tau_0} A_p L + F_f = [(dp/dx)_{\tau_0} + (dp/dx)_{\tau_0 = 0}] A_p L$$ \hspace{1cm} (4.6)

4.2 MR Damper Magnetic Circuit Design

For completeness, the description of the magnetic circuit design described in the Lord
Corporation Engineering Note (1999b) is summarized in this section. The MR damper magnetic circuit typically uses low carbon steel, which has a high magnetic permeability and saturation, as a magnetic flux conduit to guide and focus magnetic flux into the fluid gap. Tasks in the design of a magnetic circuit is to determine necessary amp-turns \((NI)\) for the magnetic circuit. An optimal design of the magnetic circuit requires to maximize magnetic field energy in the fluid gap while minimize the energy lost in steel flux conduit and regions of non-working areas. The total amount of steel in the magnetic circuit also needs to be minimized. However, sufficient cross-section of steel must be maintained such that the magnetic field intensity in the steel is very low.

The typical design process for a magnetic circuit is as follows:

1. Determine the magnetic induction \(B_f\) in the MR fluid to give desired yield stress \(\tau_0\) (Fig. 4.1a).

2. Determine the magnetic field intensity \(H_f\) in the MR fluid (Fig. 4.1b).

3. The total magnetic induction flux is given by \(\Phi = B_f A_f\), where \(A_f\) is the effective pole area including the fringe of magnetic flux. Because of the continuity of magnetic induction flux, the magnetic induction \(B_s\) in the steel is given by

\[
B_s = \frac{\Phi}{A_s} = \frac{B_f A_f}{A_s}
\]  

(4.7)

4. Determine the magnetic field intensity \(H_s\) in the steel using Fig. 4.1c.

5. By using Kirchoff’s Law of magnetic circuits, the necessary number of amp-turns \((NI)\) is

\[
NI = \sum H_i L_i = H_f g + H_s L
\]  

(4.8)
Figure 4.1: Basic magnetic circuit design procedure (Engineering Note 1999b).
where \( g \) = total length of gaps (equal to \( 2h \); refer to Fig. 4.2), and \( L \) = length of steel path which is equal to \( L_s + L_c \).

Other effects should also be considered during the circuit design process, such as nonlinear magnetic properties of MR fluid and steel; possible losses at junctions and boundaries; limits on voltage, current, and inductance; possible inclusion of permanent magnets for fail-safe operation; and eddy currents.

4.3 Practical Design Considerations

During the design of the MR damper with prescribed performance, practical problems, such as damper piston centering and voltage surge suppression, must be overcome. In the following sections, causes of these problems are discussed, and resolutions are given.

4.3.1 MR damper piston centering

Commonly, the MR damper piston does not remain centered during operation. This

\[ \text{Figure 4.2: Magnetic circuit of MR dampers.} \]
may be due to either manufacturer error or side loads due to inappropriate installation (which may result in non-uniform temperature increases and local overheating, bearing malfunction and leakage, or scratching of the insulation and causing a short in the magnetic coil).

To overcome this problem, a total of 8 bronze bearings are installed on the large-scale 20-ton MR fluid damper considered in this dissertation. The schematic of the piston head with the bearings installed is shown in Fig. 4.3. The bearings have a very close fit with the damper cylinder housing and keep the piston centered. Moreover, bronze is softer than steel and will not scratch the cylinder surface.

### 4.3.2 Voltage surge suppression

MR dampers utilize the current flowing through the damper coil to generate a magnetic field and thus a yield stress in the MR fluid. The current can be provided by either a voltage source or a current driver. If the MR damper or the power supply suddenly has a connection break, causing an open circuit, current flow through the coil will abruptly stop. According to Faraday’s law of induction, a voltage developed across the coil is given by

![Figure 4.3: Schematic of piston head installed with bronze bearings.](image-url)
As can be seen from Eq. (4.9), the voltage is proportional to the time rate of change in current flow. When the connection breaks, the current change rate is very high; this can cause a voltage surge across the coil, especially in the MR damper coil due to its large inductance. This voltage surge will break down the coil insulation and cause an electric short. As a result, the coil cannot generate a sufficient magnetic field in the MR fluid flow gap, and the damper force reduces significantly.

To protect the coil from such voltage surges, a transient voltage suppressor (TVS) connected with damper coil in parallel can be used to limit voltage to acceptable levels. Usually, TVS has a very large resistance when the voltage is below its threshold. However, when its threshold voltage is exceeded, the TVS begins conducting due to the avalanche breakdown of the PN junction, and it clamps the voltage to a harmless level. TVS restores to the non-conducting mode after voltage drops below its threshold level.

Fig. 4.4(a) shows a schematic of the electric circuit of the damper coil installed with a bidirectional transient voltage suppressor. Under normal operation, the current flowing through the TVS is very small (<5 mA), acting like an open switch (Fig. 4.4(b)). When a wire connection breaks, the voltage across the coil will exceed the threshold and the TVS begins conducting (Fig. 4.4(c)). Therefore, the voltage across the coil is suppressed to a safe operating level, and the energy previously stored in the coil is dissipated by the resistance of the damper coil itself. Note that for a multi-stage coil, a TVS is installed at each coil to prevent the connection breaks between coils.

For the 20-ton large-scale MR damper, the magnetic coils have a total resistance of:

$$V(t) = -L \frac{di}{dt}$$  

(4.9)
about 20 ohms and a nominal operating current of between 0 and 2 A if connected in series. However, the coils can tolerate a current of up to 8 A for a short duration. An MSC 1.5KE91CA bidirectional transient voltage suppressor is chosen; this TVS has a maximum clamping voltage of 125 volts and a peak pulse power dissipation of 1500 watts. After the TVS is installed, the maximum coil current will remain below 125/20 = 6.5 A, thus allowing the coil to operate safely.