Design Considerations of Electrorheological Damper

Thae Su Tin*, Dr.Aung Ko Latt**

* Lecturer, Department of Mechanical Engineering, Technological University (Kyaukse), Myanmar
** Associate Professor, Department of Mechanical Engineering, Mandalay Technological University, Myanmar

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Abstract- Damper is simply a shock absorber which is a spring or hydraulic device used in the vehicles suspension system. A car spring will extend and release the energy it absorbs from the bump at an uncontrolled rate if a damping structure is not present. The normal application of ER fluids is in fast acting hydraulic valves [10] and clutches. The other applications of ER are in brakes [6] and shock absorbers [5] which can be thought of as closed hydraulic systems where the shock is used to try to pump fluid through a valve. The vibration damper is also an essential part of the automobiles suspension system. Suspension system is the combination of various types of spring which include leaf springs, coil springs, shock absorbers, air springs and torsion bars. These are four sets of suspension springs in each vehicle.

This paper is intended to express design considerations of ER damper for Land Cruiser. The purpose of the damper is to control spring and suspension movement. In this paper, the type of damper used is the twin-tube type applied with electrorheological fluid and nitrogen gas. The main purpose of this research paper is how to consider and design calculation of ER damper from the required known data such as piston diameter, rod diameter, ER liquid density, applied electric potential and moderate damper speed. This data had been applied in the design calculations. In this paper, it had been calculated the volumetric flow rate through the tube, the viscous pressure drop, shear damper force and damping force. From the calculated result, the shear damper force is 4 k Pa. The viscous pressure drop is 1.731 M Pa and damping force is 2270 N. In practical use, the damper force is in the range of 250-5000 N.

***Index Terms*-** Damping force, electrorheological fluid, suspension system, viscous pressure drop

I. INTRODUCTION

Electrorheological fluid, composed of dielectric particles suspended in insulating oil, is a type of smart material that can be utilized as a two-phase system namely fluid phase or solid phase. The viscosity of ERF can vary by a few orders of magnitude under the application of an external electric field. If the field is sufficiently strong, ERF can solidify into an anisotropic solid boasting a yield stress befitting its strength. The change in rheological characteristics usually is accomplished within 10 ms and is reversible. Hence, ERF has utility as an electrical–mechanical interface [1-3] for potential active-control clutch, damper, and valve applications [4-6], and is denoted smart. These days, transportation is increasing with continuing population growth and industrial expansion. The suspension system of a car is one of the car's most integral parts. An automotive suspension supports the vehicle body on the axles. The frame and body of the automobile are mounted on the front and rear axle not directly but through the springs and shock absorbers. The suspension system prevents the car body from shaking and vibrating from road noise, and also helps to sustain wheel contact with the ground, interacts with the steering system to provide vehicle control, and aids in maintaining a comfortable car ride. A basic suspension system includes springs and dampers. The primary purpose of the vibration damper is to control spring and suspension movement. This action is received by transforming the kinetic energy of suspension movement into thermal energy, or heat energy, to be dissipated through the hydraulic fluid. Vibration damper are also oil pumps in which a piston is attached to the end of the piston rod. It works against the hydraulic fluid in the pressure tube. Figure 1 show the piston, piston rod and base valve in vibration damper. When the suspension travels up and down, the hydraulic fluid is forced through tiny holes called orifices inside the piston. However, these orifices let only a small amount of fluid pass through the piston. This action slows down the piston and which in turn slows down the spring and suspension movement.

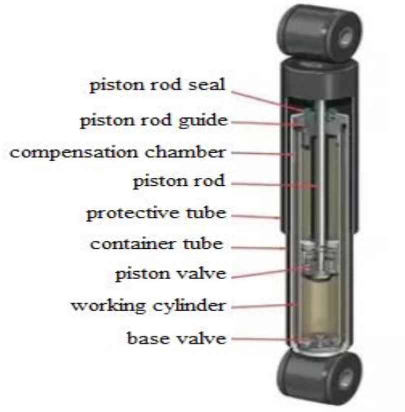

Figure 1**.** Electrorheological Damper

II. CLASSIFICATION OF DAMPERS

The dampers can be classified into three main groups according to their construction, operation and medium.

Classification by operation

(1) Single action type

(2) Multiple-action type

Classification by construction

(1) Twin- tube type

(2) Mono-tube type

Classification by working medium

(1) Hydraulic Type

(2) Gas-filled type

Among these three groups, multiple action type operations with mono-tube or twin- tube damper are mostly used in modern cars. In hydraulic type, damper can be classified into two. They are electrorheological damper and magnetorheological damper. In this research paper, electrorheological damper is used for good situation of shock absorption [5].

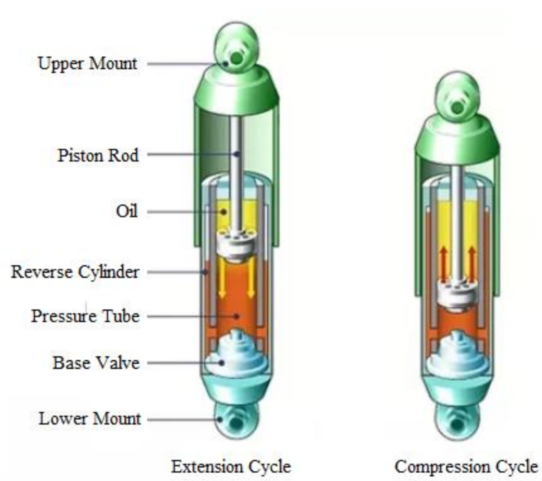

Figure 2**.** Function of Electrorheological Damper

III. THEORY FOR ELECTRORHEOLOGICAL DAMPER

A conventional damper oil is considered as a Newtonian liquid because it has simple viscosity, albeit temperature dependent. ER liquid has a yield stress and a post-yield marginal viscosity. Both of them are dependent on the applied field. So, they are characterized by two parameters, the yield shear stress τ_Y and the subsequent marginal viscosity μ. In practical use, the main operational parameter is to control the variation of the yield stress. The annular flow design such as Figure 3 uses a free piston to accommodate oil expansion and the rod insertion volume. A conventional double-tube configuration could be used although there would then be a total of three concentric tubes. In this design, it is assumed that the force will be controlled entirely by the electric field, i.e. there are no conventional valves in the piston. The material of the piston of the electrorheological damper is soft iron or steel [8].

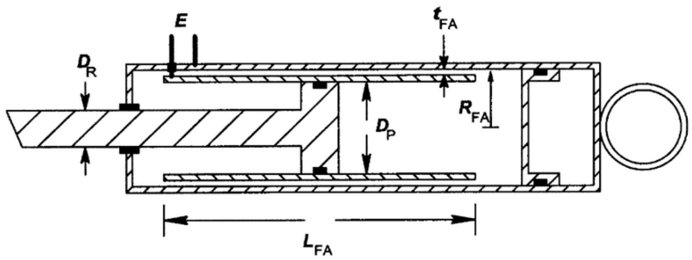

Figure 3. Basic Design of an Electrorheological Damper

In practical design value, the following data are used: D_R = 16 mm, D_P = 30 mm, R_{FA} = 25 mm, t_{FA} = 0.5 mm, L_{FA} = 280 mm. Shock absorber is designed by using the parameters shown in Table I.

Table I. Characteristics of Electrorheological Liquid [5]

Specifications	**Symbols**	**Units**	**Values**
Moderate damper speed	V_D	m/s	0.5
Applied electric potential	E	V	5×10^3
Max: shear stress	$\tau_{Y\,max}$	kN/m^2	4
Density	ρ	kg/m^3	1.5×10^3
Viscosity	μ	$N\text{-}s/m^2$	4×10^{-2}

IV. DESIGN CONSIDERATIONS OF ELECTRORHEOLOGICAL DAMPER

The fluid annulus cross-sectional area, using the annulus central radius R_{FA}, can be calculated from the following equation,

$$A_{FA} = 2\pi R_{FA} t_{FA} \tag{1}$$

The piston annulus area can be calculated from the following equation,

$$A_{PA} = \frac{\pi}{4}(D_P^2 - D_R^2) \tag{2}$$

The area factor can be calculated from the following equation,

$$f_A = \frac{A_{PA}}{A_{FA}} \tag{3}$$

The mean fluid flow velocity V_{FA} in the tube can be calculated from the following equation,

$$V_{FA} = \frac{Q}{A_{FA}} \tag{4}$$

At a damper velocity V_D, the volumetric flow rate through the tube can be calculated from the following equation,

$$Q = A_{PA} V_D \tag{5}$$

For a circular or approximately circular section, the limits for Reynolds are

Re < 2000 (Laminar flow)

$Re > 4000$ (Turbulent flow) (6)

The properties of fluid flow are found to be two types of flow, laminar and turbulent. The criterion for this is the Reynolds number can be calculated from the following equation,

$$R_e = \frac{\rho VD}{\mu} \quad (7)$$

The pressure drop acts on the piston annular area so the viscous damper force can be calculated from the following equation,

$$F_{D,V} = A_{PA} P_V \quad (8)$$

The viscous pressure drop can be calculated from the following equation,

$$P_V = \frac{6\mu L_{FA} Q}{\pi R_{FA} t_{FA}^3} \quad (9)$$

The damper coefficient C_D can be calculated from the following equation,

$$C_D = \frac{F_{DV}}{V_D} \quad (10)$$

To initiate any movement of the ER fluid, a force must be applied axially to the fluid to overcome the total shear resistance. This ER fluid shear force in the annulus can be calculated from the following equation,

$$F_{FA,ER} = 2(2\pi \quad R_{FA}) L_{FA} \tau_{ER} \quad (11)$$

To obtain the ER effect, an applied electric potential difference between the inner and outer tubes gives a radial electric field strength E/t_{FA} (V/m). This gives the ER liquid a yield shear stress τ_{ER} according to

$$\tau_{ER} = C_{\tau E} \frac{E}{t_{FA}} \quad (12)$$

where $C_{\tau E}$ is a coefficient depending only on the properties of the ER fluid, e.g. the concentration of particles, but not on the damper geometry. The ER shear stress acts over the two cylindrical surfaces of the fluid in the annulus. This force is produced by a pressure drop acting on the fluid annulus cross-sectional area. The effective ER shear pressure drop can be calculated from the following equation,

$$P_{ER} = \frac{F_{FA,ER}}{A_{FA}} \quad (13)$$

This resistance pressure acts on the piston annulus area, so the resulting ER shear damper force can be calculated from the following equation,

$$F_{D,ER} = P_{ER} A_{PA} \quad (14)$$

The effective damping coefficient can be calculated from the following equation,

$$C_E = \frac{2L_{FA} A_{PA} C_{\tau E}}{t_{FA}^2} \quad (15)$$

The quadratic damper force coefficient C_Q is given approximately by

$$C_Q = \frac{1}{2} \rho \alpha f_A^2 A_{PA} \quad (16)$$

The damper extension force can be calculated approximately by

$$F_D = C_D V_D + C_Q V_D^2 + C_E E \quad (V_D > 0) \quad (17)$$

In this paper, the net weight of vehicle is 2230 kg and gross vehicle weight is 2690 kg. In today's standard size automobile, the weight of unsprung components is normally in the range of 13 to 15 percent of the vehicle net weight. For Land Cruiser car, the ratio of the unsprung weight to vehicle weight is 0.15.

Vehicle Weight = Sprung Weight + Unsprung Weight (18)

Unsprung Weight can be calculated from the following equation,

$M_u = 2230 \times 0.15$
$= 334.5$ kg

Sprung Weight can be calculated from the following equations.

For full load,

$M_s = 2690 - 334.5$
$= 2355.5$ kg

For empty load,

M_s = 2230 –334.
= 1895.5 kg

Force on each shock absorber can be calculated from the following equation,

$$W = m \times g \tag{19}$$

Load on each shock absorber can be calculated from the following equation,

$$m_s = \frac{M_s}{4} \tag{20}$$

Direct shear stress due to force acting on the shock absorber can be calculated by the following equation,

$$\tau = \frac{\text{Load}}{\text{cross} - \text{section area of the piston}} \tag{21}$$

where, W = force on each shock absorber
D_p = diameter of piston

V. CALCULATED RESULT DATA FOR ELECTRORHEOLOGICAL DAMPER

The calculated results for electrorheological damper are shown in Table II.

Table II. Calculated Result Data for Electrorheological Damper

Specifications	Symbols	Units	Values
Annular area of the piston	A_{PA}	mm^2	5.06×10^2
The fluid annulus cross-sectional area	A_{FA}	mm^2	0.79×10^2
The area factor ratio	f_A	-	6.44
The volumetric flow rate	Q	mm^3/s	2.53×10^5
The mean fluid flow velocity	V_{FA}	m/s	3.22
The Reynolds number	R_e	-	0.36×10^2
The viscous pressure drop	P_V	MN/m^2	1.73
The viscous damper force	$F_{D,V}$	N	8.76×10^2
The damper coefficient	C_D	kN-s/m	1.75
The yield shear stress of ER liquid	τ_{ER}	$k\ N/m^2$	4
The ER fluid shear force	$F_{FA,ER}$	kN	3.52×10^5
The effective ER shear pressure drop	P_{ER}	MN/m^2	4.48
The ER shear damper force	$P_{D,ER}$	kN	2.27
The quadratic damper force coefficient	C_Q	kg/m	0.32×10^2
The effective damping coefficient	C_E	MN/V	0.45
The damper extension force	F_D	kN	2.25

VI. CONCLUSION

In this research paper, the design of electrorheological damper for four wheel drive car is described. This paper states the design calculations of shear stress and damper force for electrorheological damper. In practical use, the damper force is in the range of 250-5000 N. So, the damper force in this research paper was satisfied.

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AUTHORS

First Author–Thae Su Tin, Lecturer, ME (Mechanical), Department of Mechanical Engineering, Technological University (Kyaukse), Myanmar, dawthaesutin@gmail.com.

Second Author–Dr.Aung Ko Latt, Associate Professor, Ph.D (Mechanical), Department of Mechanical Engineering, Mandalay Technological University, Myanmar, dr.aungkolat@gmail.com.