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Experimental Investigation of Damping Force of Twin Tube Shock Absorber

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ABSTRACT

A shock absorber is a mechanical device. It's like hydraulic (oil) pump like devices It is used to damp shock impulse and use convert kinetic energy into thermal energy. The shock absorber damping effect depends on damping force. The damping force is affected by various parameters such as number of holes, damping diameter and suspension velocity. In this analysis three process parameters damping diameter(A), number of holes(B) and suspension velocity(C) were considered and their effect on damping force of shock absorber was studied. This data is then used in orthogonal array which was selected by taguchi method. Using servo hydraulic testing machine and after conducting experiments damping force was measured. And with the S/N ratio, ANOVA, Regression analysis optimum parameter values can be obtained and confirmation experiments were carried out. The experiment was conducted on Twin tube shock absorber.

Keywords : Damping Force, Twin Tube Shock Absorber, Process Parameters, Taguchi Method.

I. INTRODUCTION

A shock absorber also known as is a mechanical or hydraulic device designed to absorb and damp shock impulses. It works on principle of converting kinetic energy into another form such as heat which is afterward released (dissipated) which is then dissipated. The most commonly used shock absorbers are a form of dashpot.

Twin tube type shock absorber also known as a "two-tube" shock absorber, this device consists of two nested cylindrical tubes, an inner tube and an outer tube. The inner tube is called "working tube" or the "pressure tube" and outer tube called the "reserve tube". At the inside, the bottom section a device mounted known as compression valve or base valve. When the piston is moved up or down by bumps in the road, hydraulic fluid moves between different chambers via "orifices" or small holes in the piston and via the valve, converting the "shock" into thermal energy which was dissipated.
Twin tube type shock absorber consists of two tubes like inner tube and outer tube. Also, it consist components like piston, spring, retracting spring, piston plate, piston rod, shims etc. Out of these components piston plate has holes called as damping holes of different diameter which plays more important role in damping effect along with the suspension velocity. To achieve maximum damping force, optimisation is done by varying process parameters such as, A) Number of damping holes B) Damping diameter C) Suspension velocity by using L9 orthogonal array of Taguchi method.

The main objective of optimization of damping force is to provide comfort ride and safety driving for passenger.

Using taguchi method test parameters was optimized for maximum damping force. It is also proved that signal to noise ratio is used to optimize various process parameters.

II. METHODS AND MATERIAL

Theory

System Model

In Fig.1 shows the basic model of mass spring damper system for suspension and Twin tube rear shock absorber model.

In this system mass is represented by m, the suspension spring rate represented by K and damping coefficient is represented by C.

This system can be described by the following equation:

$$m \cdot x'' + C \cdot x' + K \cdot x = 0$$

This definition states that the sum of m (suspended mass) times its x'' (acceleration), x' (the speed of the mass) multiplied by C (a damping constant) and x (the mass displacement) times K (a spring rate) equals to zero.

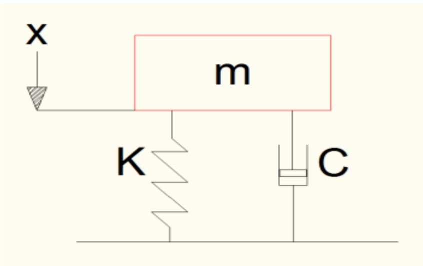


Figure 1. Mass – Spring – Damper system

Elements of Twin Tube Rear Shock Absorber

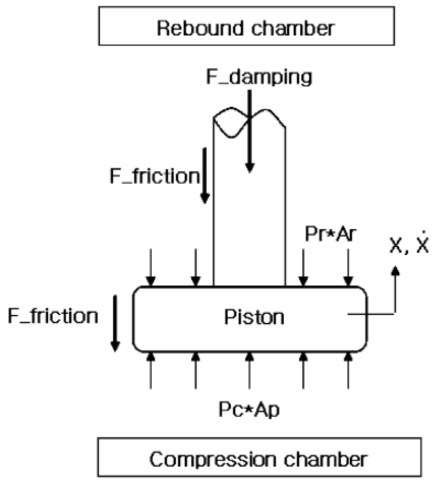
Figure 2. Elements of Twin tube rear shock absorber

1. Spring Cover Top.
2. Cylinder-Reservoir tube (Outer).
3. Spring Adjuster.
4. Axle Eye.
5. Inner helical Spring-Helper Spring.
6. Outer Helical Spring-Main Spring.
7. Spring Supporter.
8. Spring Seat.
9. Inner Tube-Reservoir.
10. Piston-Assembly.
11. Chassis Eye.
12. Base Valve.

Basically the shock absorber consists of a piston which reciprocates up and down in a fluid-filled cylinder. The cylinder is fixed to the axle or, wheel suspension, and the piston is connected via the piston rod to the vehicle frame. As the piston is forced to move with respect to the cylinder, a pressure differential is developed across the piston, causing the fluid to flow through number of holes and valves in the piston. The portion of the cylinder below the piston is known as the compression chamber and the portion of the cylinder above the piston is known as the rebound chamber. And the volume which surrounds the cylinder is known as the reservoir chamber. The reservoir chamber partially filled with a gas phase, normally air and is partially filled with fluid. The fluid passes through the body valve assembly at the bottom of the compression chamber (shown in fig 2) between the compression and reservoir chambers.

Damping force

The damping force ($F_{damping}$) of shock absorber is determined by the forces acting on the piston. And the friction forces are another factor that determines damping force Fig 3. Shows free body diagram of the piston considering the damping force.



Figyre 3. Free Body Diagram of piston for Damping Force

By considering the forces acting on the piston, the damping force can be obtained as follows:

$$F_{damping} = PrAr - PcAp \pm F_{friction}$$
$$Ar = Ap - Arod$$

where $F_{damping}$ is a damping force. $F_{friction}$ is the friction force that is acting on piston rod.

Experiment Setup Steps

An experiment was carried out on servo hydraulic testing machine.

The test system contains servo control system, function generator, signal acquisition system security monitoring system, digital A/D interface system, servo valve driver and the twin-tube hydraulic shock absorber.

Figure 4. Servo Hydraulic Testing Machine

The procedure for setup of shock absorber is as below

- Fixing the shock absorber: The lower end of a shock absorber is vertically clamped to the hydraulic servo-platform the upper end is connected to the rigid beam equipped with force sensor. The shock absorber is adjusted along the vertical direction to make sure that piston does not produce eccentric wear during loading process. Then the initial position of servo-console should be adjusted to ensure the piston locate in the middle of effective stroke.
- Loading the shock absorber: The excitation sampling frequency, frequency and amplitude are all typed into computer. The driving signal of sinusoidal displacement is produced through a function generator. The digital A/D interface is used to amplify signal and that amplified signal to make servo platform excite the shock absorber according to pre input frequency and amplitude.
- Collecting the data: Because the excitation method is displacement driving, the displacement signal of the shock absorber piston can be directly obtained by pre-input signal. The damping force can be recorded through force sensor on rigid beam.

Experiment Details

1) Design of experiments: Well organised experimental procedure is needed to identify system performance and to evaluate effect of input parameters on objective parameter. Traditional methods will increase number of experimentations. Taguchi method is used to identify optimal suspension parameter for maximum damping force. Taguchi method is an efficient tool for acquiring optimal process parameters. In this method, the number of experiments is reduced. In this method, two important tools are used: (1) orthogonal array and (2) signal-to noise ratio. In this study we have consider 3 factors which affect majorly on quality characteristic such as (A) Damping Diameter, (B) Number of damping holes (C) Suspension velocity. The design of experiment was carried out by Taguchi methodology. In this technique the main objective is to optimize damping force of rear suspension that is influenced by various process parameters.
2) Selection of control factors: As damping force has adverse effect on riding comfort, driving safety and vehicle stability. So the damping force was considered as a response parameter for experimentation.
3) Selection of orthogonal array: An orthogonal array for process design is applied on the knowledge of control factors and levels. The number of experiments can be reduced using orthogonal array In this study, L9 orthogonal array have been selected This orthogonal array has three columns and nine experiment Since 3 controllable factors and three levels of each factor were considered L9 (3**3) Orthogonal Array was selected for this study.
4) Process parameters: Twin tube shock absorber of two wheeler selected for experimentation. The experiments were carried out on Servo Hydraulic test system for damping force testing. There are three input controlling factors selected as different damping diameter, different number of holes and different suspension velocity having three levels. Details of parameters and their levels used shown in the table1

Table 1. Process parameters and levels

A	Damping Dia.(mm)	1.8	1.9	2.0
B	No. of damping holes	4	6	8
C	S-Velocity(m/s)	0.3	0.5	1

Table 2. Layout for experimental design

Expt. No.	A	B	C	Result (Damping Force) N
1	1.8	4	0.3	400
2	1.8	5	0.5	500
3	1.8	6	1	600
4	1.9	4	0.5	500
5	1.9	5	1	650
6	1.9	6	0.3	350
7	2	4	1	600
8	2	5	0.3	300
9	2	6	0.5	450

III. RESULTS AND DISCUSSION

A. Signal-to-Noise (S/N) Ratio Analysis

The signal-to-noise (S/N) ratio is then derived from the loss function. There are three types of S/N ratios depending upon type of characteristics Lower is better (LB), nominal is best (NB), higher is better (HB). In vehicle suspension system higher damping force is as a sign of better ride quality. Therefore 'HB' is chosen for the damping force and it is calculated as the logarithmic transformation of the loss function as shown below. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted.

In this study, in order to minimize the defects, higher is better S/N ratio is chosen. Higher is better S/N ratios are computed, and the values are recorded

$$\frac{S}{N} = -10\log\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$$

Where, n = number of repetitions or observations
yi = the observed data.

Table 3. S/N Ratio analysis of Damping Force

Exp. no.	A	B	C	Result (Damping Force)	S/N Ratio
1	1.8	4	0.3	400	52.0412
2	1.8	5	0.5	500	53.9794
3	1.8	6	1	600	55.563
4	1.9	4	0.5	500	53.9794
5	1.9	5	1	650	56.2583
6	1.9	6	0.3	350	50.8814
7	2	4	1	600	55.563
8	2	5	0.3	300	49.5424
9	2	6	0.5	450	53.0643

Higher value of S/N ratio corresponds to optimal level of input parameter. From table 3 it is cleared that optimal input parameter are damping diameter at level(2), number of holes at level(2), suspension velocity at level(3). i.e. damping diameter (1.9 mm), No. of Holes(5), and suspension velocity (1 m/s).

Table 4. Estimated model coefficient for S/N Ratio

Term	Coeff.	SE Coeff.	T	P
Constant	53.4303	0.2204	242.422	0
Dia 1.8	0.4309	0.3117	1.383	0.301
Dia 1.9	0.2761	0.3117	0.886	0.469
no. of h 4	0.4309	0.3117	1.383	0.301
no. of h 5	-0.2607	0.3117	-0.836	0.491
s.veloci 0.3	-2.6086	0.3117	-8.369	0.014
s.veloci 0.5	0.2441	0.3117	0.783	0.516

Summary of Model-

S = 0.6612 R-Sq = 97.9% R-Sq(adj) = 91.5%

Table 5. Response table for signal to noise ratio larger the better

Level	Diameter (mm)	No. of hole	Suspension velocity
1	53.86	53.86	50.82
2	53.71	53.17	53.67
3	52.72	53.26	55.79

Delta	1.14	0.69	4.97
Rank	2	3	1

B. Analysis of Variance (ANOVA)

ANOVA is objective decision making for determining the average performance of group of parameter tested and it is helpful in determining the significance of all parameters.

The analysis of variance was used to identify the important input parameters which effects damping force. Once the experiment has been conducted, the ANOVA is carried out using the results of the experiments by making use of minitab14 software. The significant factors in the shock absorber defects were determined. The analysis of the experimental data is carried out using the software MINITAB 14 specially used for design of experiment applications. In order to find out statistical Significance of various factors like damping diameter (A), number of holes (B), and suspension velocity (C), and their interactions on damping force, analysis of variance (ANOVA) is performed on experimental data.

Table 6. Analysis of variance for S/N Ratios

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
A	2	2.2855	2.2855	1.1427	2.61	0.277
B	2	0.848	0.848	0.424	0.97	0.508
C	2	37.366	37.366	18.683	42.7	0.023
Error	2	0.8744	0.8744	0.4372		
Total	8	41.374				

The results of ANOVA are shown in table 6 it is clear that the parameters A, C, and D significantly affect the damping force.

Larger F- value indicates that the variation of process parameters makes a big change on the performance. The last column of the table shows that p-value for the individual control factors. Smaller the p-value, greater the significance of the parameter. The ANOVA table for S/N ratio (Table 6) indicate that, the damping diameter (p=0.277), Number of hole (p= 0.508) and suspension velocity (p=0.023) in this order, are significant control factors affecting damping force. It means the suspension velocity is the most significant factor followed by damping diameter and number of holes.

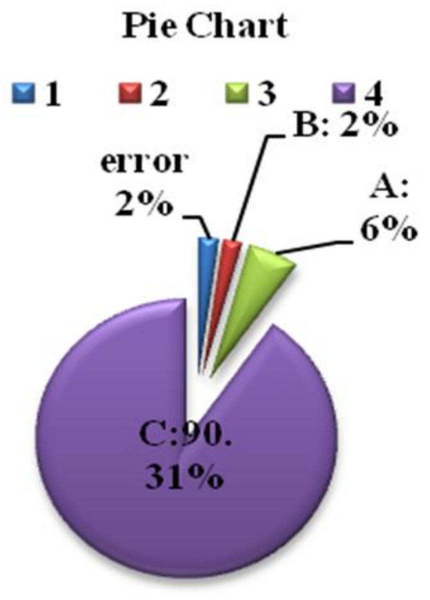
C. Percent Contribution

Percent contribution to the total sum of square can be used to evaluate the importance of a change in the process parameter on these quality characteristics.

Percent contribution (P) = (SS'A / SST) *100

Table 7. Optimum condition and Percentage contribution

Sr. No	Factors	Level Description	Level	Contribution (%)
1	A: Damping Dia.	1.9	2	5.52
2	B:No. of Hole	5	3	2.04
3	C: Suspension Velocity	1	1	90.31



D. Regression Analysis

Regression analysis is used for explaining or modelling the relationship between a single variable Y, called the response, output or dependent variable, and one or more predictor, input, independent or explanatory variables Mathematical models for process parameters such as damping diameter, Number of hole and suspension velocity were obtained from regression analysis using MINITAB 14 statistical software to predict damping force.

The regression equation is

$$Y = 826 - 250*A - 16.7*B + 359*C$$

S = 42.5923   R-Sq = 92.1%   R-Sq (adj) = 87.4%

If we put optimum parameters which are drawn by ANOVA in equation 1 it will give optimum value of quality characteristic which will maximum Damping force.

$$Y = 826 - 250*A - 16.7*B + 359*C$$

$$Y = 826 - 250*1.9 - 16.7*5 + 359*1$$

Y = 626.5 N ………. (Predicted by Regression Equation)

In multiple linear regression analysis, R2 is value of the correlation coefficient and should be between 0.8 and 1. In this study, results obtained from damping force in good agreement with regression models (R2>0.80).

E. Confirmation of Result

In Order to test the predicted result, confirmation experiment has been conducted by running four trials at the optimal settings of the process parameters determined from the Analysis i.e. A2 B2 C3 Error between experimental valued and predicted values by regression equation is (1.078%) which is less than 5%.

Obs.	Trial			Avg. damping force (N)			S/N Ratio
	1	2	3	Expe.	Predi.	% Error	
1	630	650	620	633.3	626.5	1.078	52.99

Hence this mathematical model is feasible and effective. The results are shown in above table and it is observed that the average Damping force i.e. 634 and average S/N Ratio 52.99 which falls within predicted 80% Confidence Interval.

IV. CONCLUSION

It is found that taguchi method of parameter design can be performed with minimum number of experimentations and it provides simple, efficient, systematic methodology for optimizing the process parameters. The Taguchi method was applied to find an optimum setting of the damping force parameters process. The result from the Taguchi method chooses an optimum solution from combinations of factors

The results are summarized as follows:

1) Parameters like damping diameter, number of holes and suspension velocity are selected for maximization of damping force.
2) The largest impact on the characteristics of the damping force is from parameters like suspension velocity followed by damping diameter, number of holes.
3) From results we come to conclusion that damping diameter at level 2, the number of holes at level 2, suspension velocity at level 3 is recommended for maximization of damping force. The results of confirmation experiment well satisfied with optimal setting.
4) The result of present investigation is valid within specified range of process parameters.
5) Also the prediction made by Regression Analysis is in good agreement with Confirmation results.

The optimal levels of Damping force process parameters for optimum damping force are:

Parameters	Optimum value
Damping Diameter (mm)	1.9
Number of Hole	5
Suspension Velocity (m/s)	1

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