DETERMINATION OF DAMPING COEFFICIENT OF AUTOMOTIVE HYDRAULIC DAMPER USING SINUSOIDAL TESTING

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Abstract

Automotive Damper is one of the important component in vehicle suspension system. It is used to ensure Vehicle safety and Driving comfort. As Damper behaves highly nonlinear while in operation its damping characteristics affects the design and overall performance of the vehicle. Objectives of this study is to experimentally find equivalent Damping coefficient of Dampers under test, it is useful parameter to evaluate damping force which is product of damping coefficient and velocity in simplest analysis of Damper. Firstly, working principle and roll of Damper is stated. Then the detail Experimentation procedure along with test specimens is given. The Dampers are tested under sinusoidal displacement excitation with different amplitudes and frequencies corresponding to road condition and test bench specification on MYTIDYNE servo hydraulic test bench at ARAI Pune. Results from experimentation is analyzed and used to evaluate Equivalent damping coefficient by using Jacobsen's approach. The evaluated results show satisfactory constant behavior over various frequency range except for very low frequency of excitation due to Friction Damping. This constant behavior can be seen from plot of Frequency versus Equivalent Damping coefficient.

Index Terms: Characteristic, Equivalent Damping coefficient, Hydraulic Damper, Sine Excitation, Vibration.

I. INTRODUCTION

The Automotive Damper is an important part of vehicle suspension system. Suspension helps to support weight, absorb and damping of road shocks, help to maintain constant tire-road contact as well as proper wheel to chassis relationship. [8] Damper considered as one of the most complex parts of the suspension to model, as the Damper behaves in a nonlinear and time-variant way, this influence braking, steering, cornering and overall stability.

A. The principle of working the twin tube hydraulic Damper could be briefly elaborated. The oil in the cylinder of Damper repeatedly flows from one chamber to other chamber through some narrow gaps of base valve and piston valve as piston is moving back and forward in the cylinder tube. As a result, the damping force is produced because of the friction generated among oil molecules because of flow restriction due to narrow gaps in valve. The damping force is proportional to Velocity however; the damping force is always designed greater in the extension than in the compression stage to quickly accommodate shocks and provide damping, in order to improve vehicle dynamic behaviors. [11]

B. Role of vibration damper: Dampers or vibration dampers are not only used in automotive suspensions but also in truck cabins, seats, steering, and as impact absorbers for vehicle bumper systems. The major roll of Damper is to dampen chassis vibration since this is the major and most significant area of application. Dampers are fitted parallel to each other in vehicle suspension system and they have the following tasks:

1) Post-vibration produced by uneven roads or driving conditions need to be damp.

2) To quickly settle road-induced wheel and axle vibration, i.e. to provide a constant tire to road contact and afterwards ensure good tracking and braking performance.

3) To prevent vehicle components from being subjected to road shocks.

4) To safeguard the occupants from road shocks.

5) To preserve the stability of the vehicle in motion as it pitch or roll.

In simplest mathematical case viscous damping is considered as product of Damping Coefficient and velocity. Evaluation of accurate damping coefficient is very complex task as damper shows nonlinear behavior while operation. Hence getting equivalent linearization of nonlinear system is procedure to get damping coefficient that gives response similar to nonlinear system also Estimation of this equivalent viscous damping factor (ξ) (EVDF) used to characterize the substitute structure is a key parameter in this design methodology. J. P. Bandstra presented comparison of the normal engineering methods of including the effects of nonlinear damping to more exact methods of solution so that the range of applicability of the normal methods may be known and the limitations of linear analysis more fully understood. [1]. J. Wallaschek described how the parameters of an equivalent linear system can be obtained directly from experimental data. Also the methods of harmonic and stochastic linearization are discussed with respect to applications in Damper dynamics. [2]. Carlos A. B. described that The dynamic response of the substitute structure is characterized by an effective stiffness and an equivalent viscous damping, simplifying considerably the dynamic problem and making this approach very desirable for design purposes. Estimation of the equivalent viscous damping factor (EVDF) is an important step in the methodology of the direct displacement based design. However, errors in the estimation of these parameters characteristics lead to consequent errors in the ductility demand of the designed elements. As a consequence, modified equations were proposed in order to estimate the EVDF to reduce the errors. [3]. R. Zaharia Presented review on some equivalent viscous damping models along with the concept for evaluation of equivalent viscous damping. [4]. Dixon J. C. in his Handbook provide detailed scheme of Testing, types of testing and Characteristics of Damper. [5] H.M. Dwairi et al. presented approach of equivalent linearization of nonlinear system response as applied to direct displacement based design. Also identified the scatter associated with Jacobsen's equivalent damping combined with the secant stiffness as utilized in Direct Displacement-Based Design, and found how improvement in the accuracy of the Direct Displacement-Based Design approach by providing alternative equivalent damping expressions. [6] M.S.M. Sani et.al Described the dynamic characteristics of a Damper. The design of interchangeable Damper test rig is developed and fabricated. conducted an Experiment to identify stiffness and damping parameter on Damper. Simulation study was performed using COSMOS motion software. Results obtained from both methods are found in good agreement [7]. A. M. Salem et. Al Presented Identification of characteristics and damping coefficient of Hydraulic shock absorber. Dynamic behavior is studied by using experimental and simulation methods. Simulation performed on ADAMS software. And Predicted characteristics are compared with results from both methods. Study shows besides damping coefficient amplitude and frequency are also key factor in damper performance [8]. Yan Cui et. Al presented a new testing and analysis methodology to obtain nonlinear characteristics of an automobile Damper. three Damper models that can be quickly fit to experimental data and used for vehicle simulation. These models are based on the understanding that the Damper is predominantly a velocity-dependent device. Further a single-post shaker test bench is introduced and the experimental procedure for the Damper testing is described. Also the influence of the Damper models on vehicle dynamics in vertical direction was analyzed [9]. Yongjie Lu et Al. Presented Structural features of hydraulic Damper. The detail scheme of testing is proposed. Tests carried out under sinusoidal and random displacement excitation. Then testing result analysis is performed. [10]

In this paper, The Front and Rear Wheel gas filled hydraulic Damper of Maruti Suzuki Swift are tested under the sinusoidal steady-state displacement excitation, with the standard test platform -in order to find Equivalent damping coefficients from experimental data. The testing data are then analyzed, the tested results show that the Damper has the typical features of non-linearity, non-symmetry and hysteresis. The Data from experimentation is first analyzed and using Jacobsen's approach equivalent Damping Coefficient is evaluated and represented in graphical form then approximate value is determined for both dampers from the range in which the damping coefficient is varied.Procedure for Paper Submission

II. EXPERIMENTAL TEST

Experimental Testing of the Gas Filled Hydraulic Damper was performed in order to Evaluate Equivalent Damping Coefficient and to fit with mathematical force model stated for Dampers that has been developed to accurately predict the force output as a function of velocity.

(a) (b)

Fig. 1. Test Specimens (a) Front Damper (b) Rear Damper

Servo-hydraulic dynamic testing system was used to collect Time, force and displacement data of the Test specimen. The physical parameters of the damper were carefully measured.

Fig. 2. Experimental Setup

A. *Test setup and Apparatus.*

Left hand Side Front and Rear Wheel gas filled hydraulic Dampers of Maruti-Suzuki Swift (2012) Model, has been tested on standard test rig (MYTIDYNE servo-hydraulic Test Rig) located at Automotive Research Association of India (ARAI), Pune. This Hardware is used in conjunction with controller MTS Flextest and MTS Flextest series 793 software interface in a computer so that the amplitude, frequency, sampling frequency and Excitation can be specified by the user. Test specimens, Test setup with equipped Test specimen and schematic diagram of test setup is shown in Fig.1, Fig.2 and Fig.3 Respectively,

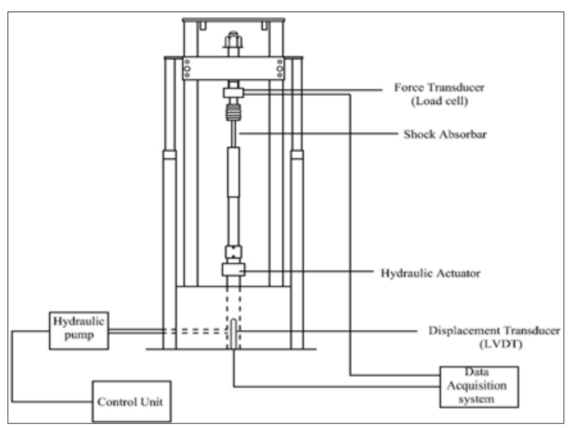


Fig.3. Schematic diagram of Test setup

B. *Testing procedure*

1) Mounting the Damper: The lower end of a Damper is vertically fixed to the hydraulic servo-test bench and the upper end is fixed to the rigid beam equipped with a load cell to sense

force. The Damper is adjusted vertically to ensure that piston does not produce eccentric movement during the loading process. Initial position of the hydraulic actuator is then adjusted to ensure the piston is in the middle of the effective stroke. [6]

2) Loading the Damper: The amplitude, excitation frequency and sampling frequency are all set into the computer software. The actuation signal of sinusoidal excitation is produced through a function generator. The amplification of signal is done by the help of digital A/D interface to make servo actuator to excite the Damper according to input data i.e. amplitude and frequency. The force produced across the damper is recorded by a load cell and the dynamometer displacement is recorded by linear variable differential transformer (LVDT).

3) Data acquisition: Because displacement driving is the excitation method used, the displacement data signal of the Damper piston can be directly recorded into system and the force generated across the damper is then recorded through the load cell fitted on the rigid beam. The computer software collects this output displacement and force data then it is put into Microsoft Excel and Matlab software interface for analysis where various operations like data smoothening, determination of velocity using time and displacement data. and Finally, Time -Displacement, Time-velocity, characteristic diagram (velocity - force) and work diagrams (Displacement -Force) are obtained for single cycle and for whole Test run.

C. *Input Data for Experimentation.*

To Obtain Damping characteristics of Dampers which generally nonlinear in nature, Experimental Test is performed under Sinusoidal excitation at various amplitude and frequency. Accordingly, these tests are carried out on Test specimens at ARAI Pune. The displacement of dynamometer under sinusoidal excitation can be calculated from the amplitude and frequency. And velocity is then determined by taking the first derivatives of the displacement. These equations are restated.

$$x(t) = X.\sin.2\pi.f.t \tag{1}$$

frequencies of excitation and amplitudes as input for experimental tests as given in Table I and Table II for Front Damper and Rear Damper respectively these combination of amplitudes are taken based on the stroke of Dampers and the frequencies are chosen depends on mainly two factors dynamometer maximum velocity that was 0.7 m/s and vehicle suspension resonance frequencies operating under normal condition.

TABLE I. INPUT DATA FOR EXPERIMENTATION OF FRONT DAMPER.

Sr. No	**Amplitude (mm)**	**Frequency (Hz)**
1	10	0.05,5,8,11
2	20	0.05,1.6,3,5
3	30	0.1,0.5,1.2,2, 3.5
4	40	1,1.2,2
5	50	0.1,0.5,1.2,2
6	60	1,1.2,1.6
7	63	0.05,1,1.5

TABLE II. INPUT DATA FOR EXPERIMENTATION OF REAR DAMPER.

Sr. No	**Amplitude (mm)**	**Frequency (Hz)**
1	10	0.05,5,8,10
2	20	1.6,3,6
3	30	0.05,0.5,1.2,2 ,3.5
4	40	1,1.2,2.5
5	50	0.5,1,1.2,2
6	60	0.05,1,1.2,1.6

III. EXPERIMENTATION RESULTS AND DISCUSSION

The data recorded from the series of Experiments for both test specimens, is Time, Displacement and the force generated across damper in the form of array, this data is further analyzed and various plots are drawn in Microsoft Excel and Matlab software for analysis. Time – Displacement Diagram, the damping characteristics curves (V-F Diagram) and work Diagrams (Force-Displacement or F–X Diagram), are obtained from Experimental test results of both Dampers, as presented below in this section. Time-Displacement plot is help us to understand how the displacement varies w.r.t time, The Characteristic curve (Velocity – Force diagram) shows nonlinear behavior in both compression and extension region with some effect of hysteresis, but it is clearly seen from this diagram that damping is kept more in extension that that of compression section also how force varies w.r.t velocity is seen from this diagram as we goes towards higher frequency of excitation the damping force become predominant as it depends upon velocity. Another plot (F-X) Diagram allow us to understand the energy dissipated by damper during its cyclic operation. In this way Experimental results and plots obtained from it will help us to understand and visualize characteristic of Damper. These various plots obtained for both Damper shows nearly similar nature which are presented below.

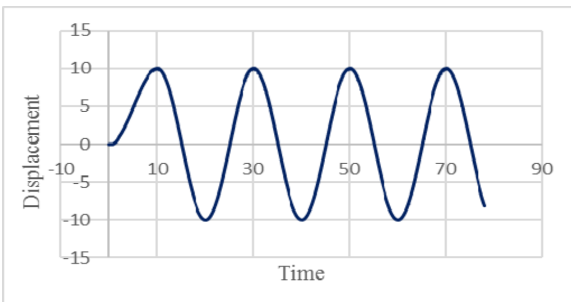


Fig. 4. Time vs Displacement for Sinusoidal Excitation for Both Test Specimen for Frequency (0.05 Hz) and 10 mm Displacement. This figure shows how the Displacement varies w.r.t Time.

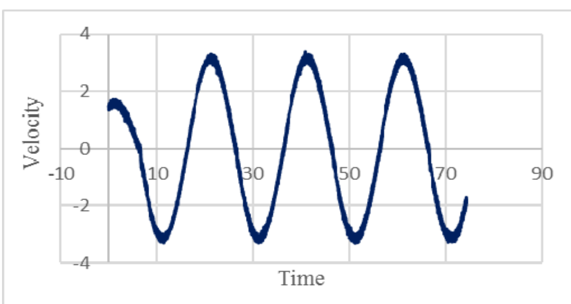
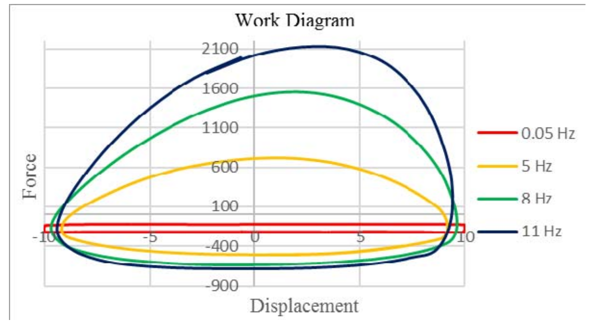
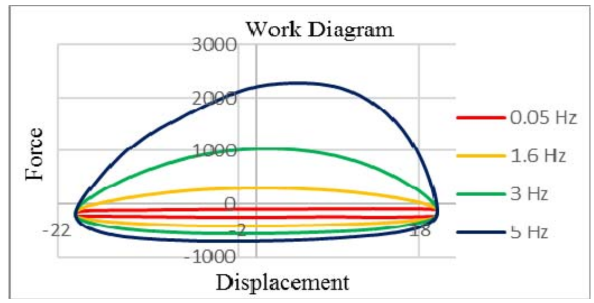


Fig. 5. Time vs Velocity for Sinusoidal Excitation for Both Test Specimen for Frequency (0.05 Hz) and 10 mm Displacement. This figure shows how the Velocity varies w.r.t Time.

A. Experimentation Results analysis of Front Damper



(a)



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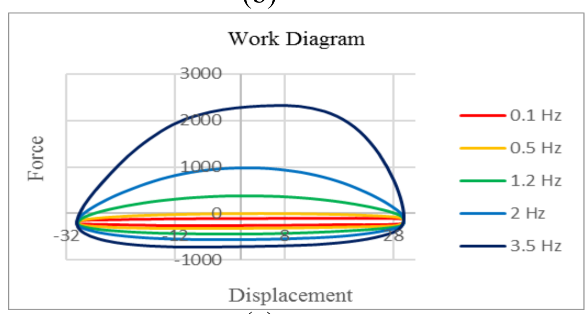

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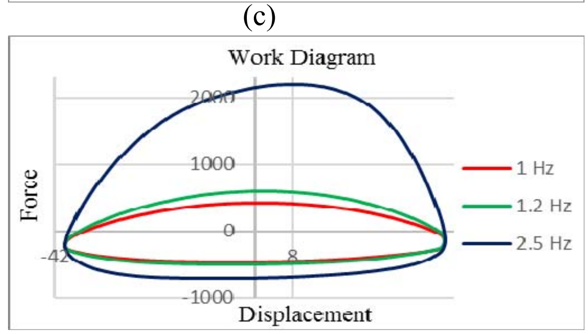

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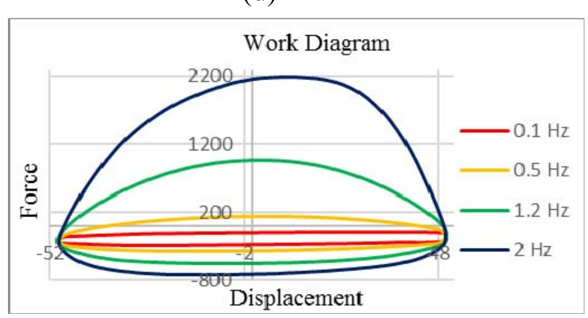
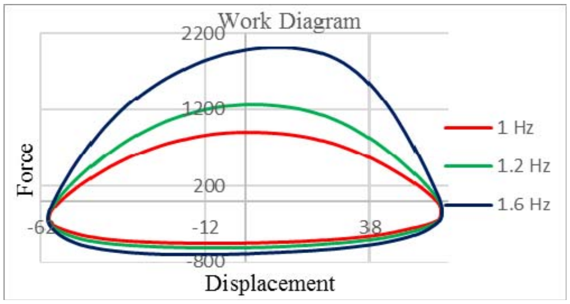


(e)



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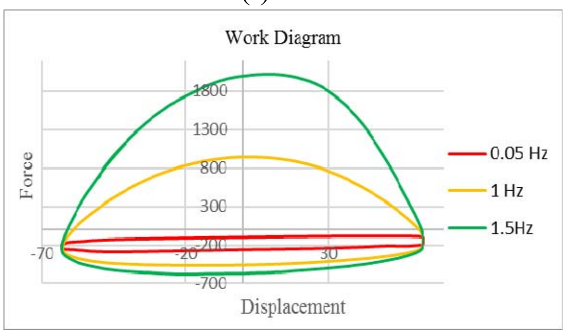
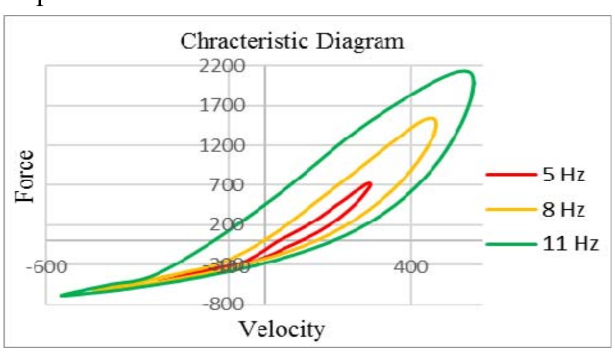
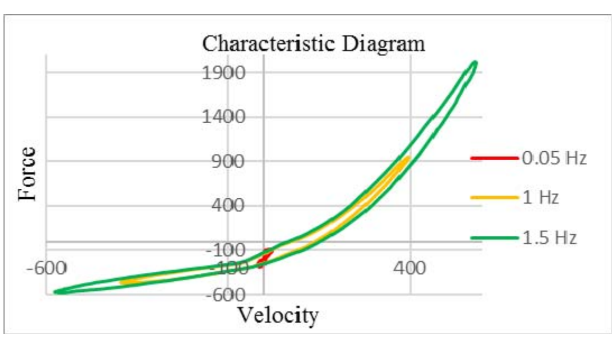


(g)

Fig. 6. (a),(b),(c), (d), (e), (f), (g) are Work Diagram for 10 mm, 20mm, 30mm, 40mm, 50mm, 60mm, 63mm amplitude respectively (Front Damper).In These figures, the area under the curve shows work done or Energy dissipated by front damper with various frequencies and amplitude.



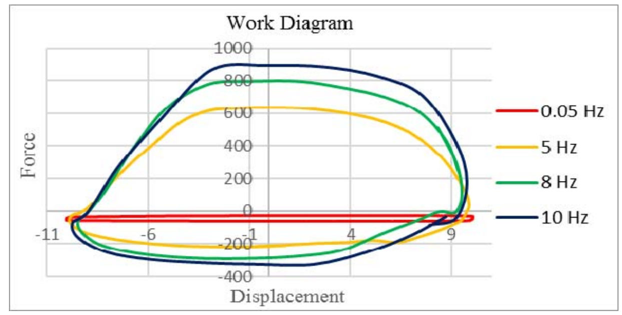
(a)



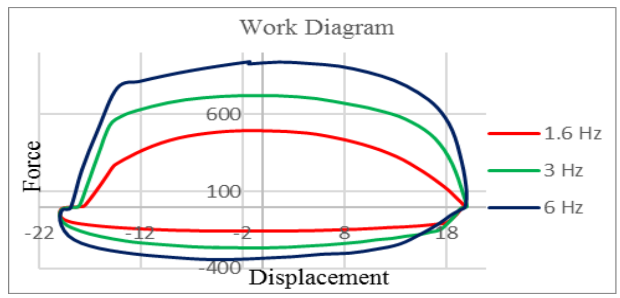
(b)

Fig. 7. (a),(b) are Characteristic Diagram for 10 mm, and 63mm amplitude respectively (Front Damper). This figures shows how the force varies with velocity, as damping force is velocity dependent force, it increases with increasing velocity.

B. Experimentation Results analysis of Rear Damper



(a)



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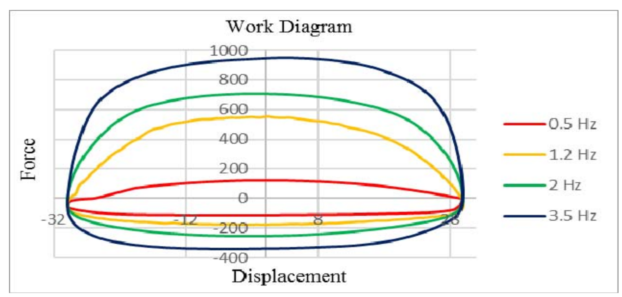

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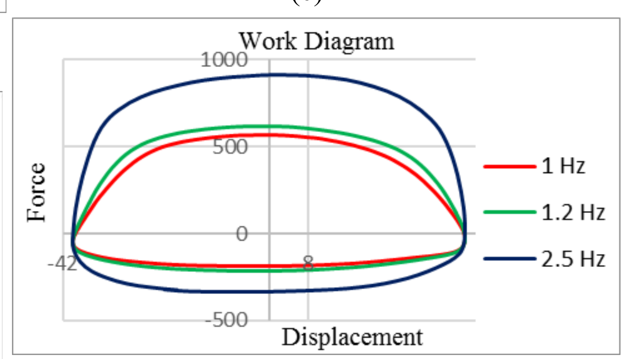

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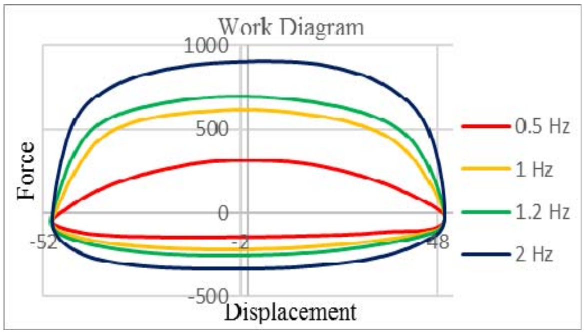

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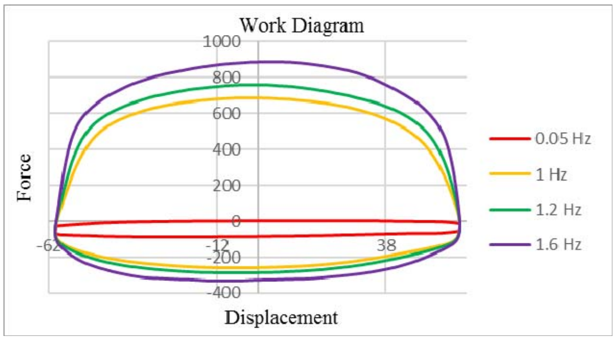
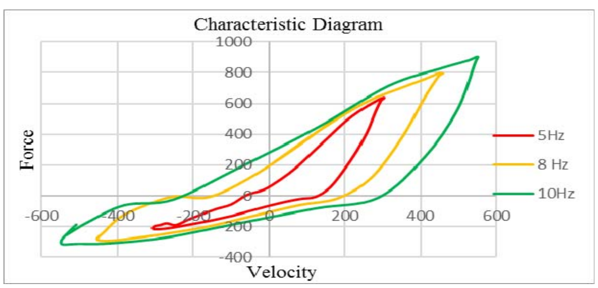
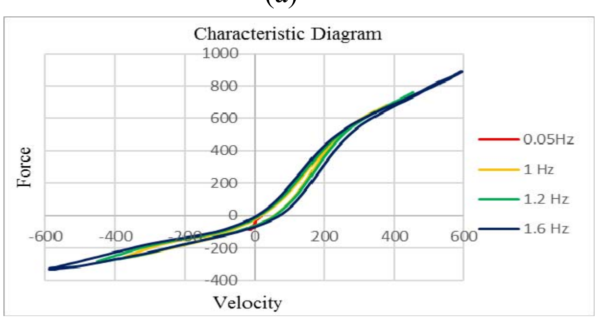


(f)

Fig. 6. (a),(b),(c), (d), (e), (f) are Work Diagram for 10 mm, 20mm, 30mm, 40mm, 50mm, 60mm, amplitude respectively (Rear Damper).In These figures, the area under the curve shows work done or Energy dissipated by front damper with various frequencies and amplitude.



(a)



(b)

Fig. 9.(a),(b) are Characteristic Diagram for 10 mm, and 60mm amplitude respectively (Rear Damper).

IV. EQUIVALENT DAMPING COEFFICIENT

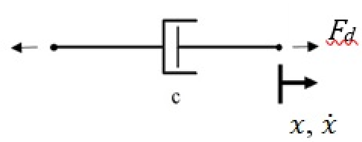
The process of evaluation of Equivalent Damping Coefficient in which the real nonlinear MDOF system of Damper is replaced by simple elastic SDOF system having equivalent damping coefficient (C_{eq}) which is approximate value of damping coefficient corresponding to real nonlinear system, that to be use to evaluate damping force in system in simplest analysis. The Equivalent elastic system is supposed to have same response as real nonlinear system under given same sinusoidal excitation. To Evaluate Equivalent Damping Coefficient most popular Jacobsen's Approach is used, who was the first author to introduced this concept. The equivalent viscous damping coefficient is determined on the assumptions that the real nonlinear Damper model and its equivalent linear system dissipates same amount of energy per cycle of response to sinusoidal excitation. As system is assumed to be subjected to harmonic excitation it can be expressed as,

$$m\ddot{x} + c\dot{x} + kx = X.\sin\omega t$$

Where,
ω = Frequency (rad/ sec)
t = time (sec)

The energy dissipated is equal to the area enclosed inside an entire loop of work diagram. The elliptical loop is obtained from the equation that describes energy dissipated by viscous damper. the Jacobsen's approach is adopted because of (1) its simplicity, (2) The ease with which the relation between hysteretic shape and equivalent damping is obtained. The concept of Jacobsen's approach is presented below.

Taking simple damper model in consideration as shown below



For Steady state system, the energy lost per cycle in a damper in a harmonically forced system may be expressed as,

$$W_d = \oint F_d.dx \qquad (2)$$

Where, F_d represents the damping force. The simplest case mathematically is that of viscous damping, where,

$$F_d = C.\dot{x} \qquad (3)$$

$$x = X.\sin.\omega.t \qquad (4)$$

Hence,

$$W_d = \oint C.\dot{x}.dx = \oint C.\dot{x}^2.dt \qquad (5)$$

where we recall that $dx = \dot{x}.dt$, Substitution of (4) into (5) yields,

$$W_d = \omega^2 x^2 \int_0^{2\pi} \cos^2(\omega t).dt = \pi.C.\omega.X^2 \qquad (6)$$

This equation gives energy dissipated by damper in one harmonic cycle

From the experimentation we got data of Displacement, Force mentioned in previous section can be represented graphically for one cycle as shown below,

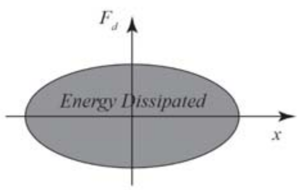


Fig. 10. Energy Dissipated by Viscous Damper in one cycle [3]

Mechanisms may be modeled as equivalent viscous dissipation by equating the work done in one cycle to that done by a viscous damper.

$$W_d = \pi.C_{eq}.\omega.X^2 \qquad (7)$$

Hence, the equivalent viscous damping coefficient (C_{eq}) is defined as,

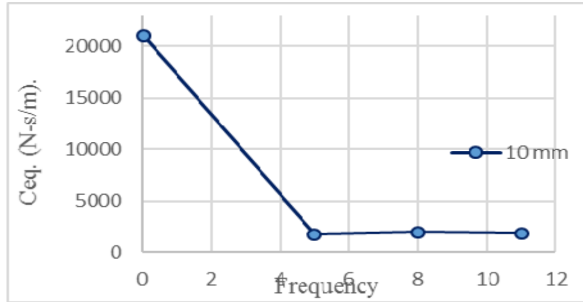
$$C_{eq} = \frac{W_d}{\pi.\omega.X^2} \qquad (8)$$

Where,

$$\omega = 2.\pi.f$$

Hence using this approach, the W_d that is area under work diagram is evaluated from experimental data using Matlab software and energy dissipated for one sinusoidal excitation is calculated by given formula and accordingly the value of C_{eq} have been evaluated and tabulated below in Table III and Table IV for Front Damper and Rear Damper respectively, also the Graphical representation this shown by plotting graph Frequency vs C_{eq} to understand the behavior of Equivalent Damping Coefficient w.r.t Frequency for various amplitude of excitations.

A. Determination of Equivalent Damping Coefficient for Front Damper

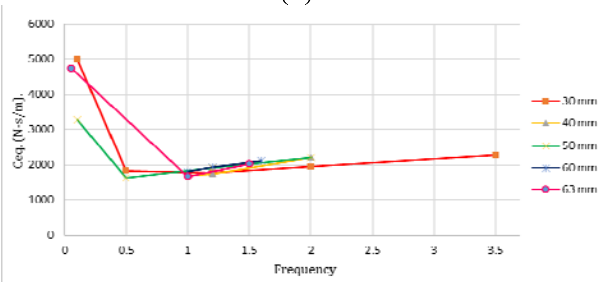


Sr. No	Amplitude (mm)	frequency (Hz)	Area under Work diagram (N. m)	Energy of a harmonic cycle	Equivalent Damping Coefficient (N-s/m)
1.	10	0.05	2.0706	9.87E-5	20979.56
2.	10	5	17.55	0.009869	1778.19
3.	10	8	31.22	0.015791	1977.28
4.	10	11	40.72	0.021713	1875.46
5.	20	0.05	5.1302	0.000395	12994.95
6.	20	1.6	22.439	0.012633	1776.21
7.	20	3	47.719	0.023687	2014.56
8.	20	5	88.762	0.039478	2248.37
9.	30	0.1	8.8613	0.001776	4987.99
10.	30	0.5	16.259	0.008882	1830.42
11.	30	1.2	37.684	0.021318	1767.68
12.	30	2	69.064	0.035530	1943.80
13.	30	3.5	140.81	0.062178	2264.61
14.	40	1	53.884	0.031582	1706.12
15.	40	1.2	65.768	0.037899	1735.34
16.	40	2.5	138.84	0.063165	2198.03
17.	50	0.1	16.095	0.004934	3261.53
18.	50	0.5	40.007	0.024674	1621.42
19.	50	1.2	113.63	0.059217	1918.85
20.	50	2	217.21	0.098696	2200.80
21.	60	1	128.79	0.071061	1812.38
22.	60	1.2	163.91	0.085273	1922.17
23.	60	1.6	239.23	0.113697	2104.08
24.	63	0.05	18.59	0.003917	4745.68
25.	63	1	130.44	0.078344	1664.95

(a)

TABLE III. EQUIVALENT DAMPING COEFFICIENT FRONT DAMPER

(b)



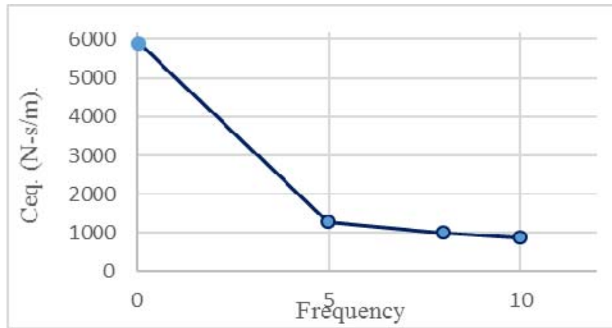
(c)

Sr. No	Amplitude (mm)	frequency (Hz)	Area under Work diagram (N. m)	Energy of a harmonic cycle	Equivalent Damping Coefficient N-s/m
1.	10	0.05	0.582374	9.87E-05	5900.69
2.	10	5	12.678	0.009869	1284.55
3.	10	8	15.47	0.015791	979.65
4.	10	10	17.34	0.019739	878.45
5.	20	1.6	19.26	0.012633	1524.57
6.	20	3	31.15	0.023687	1315.06
7.	20	6	41.41	0.047374	874.11
8.	30	0.5	10.91	0.008882	1228.24
9.	30	1.2	32.62	0.021318	1530.14
10.	30	2	47.16	0.035530	1327.31
11.	30	3.5	66.07	0.062178	1062.58
12.	40	1	47.16	0.031582	1493.22
13.	40	1.2	53.63	0.037899	1415.06
14.	40	2.5	85.18	0.078956	1078.82
16.	50	0.5	34.36	0.024674	1392.56
17.	50	1	67.36	0.049348	1364.99
18.	50	1.2	77.59	0.059217	1310.25
19.	50	2	105.42	0.098696	1068.13
20.	60	0.05	8.72	0.003553	2454.22
21.	60	1	92.01	0.071061	1294.80
22.	60	1.2	103.28	0.085273	1211.16
23.	60	1.6	123	0.113697	1081.81

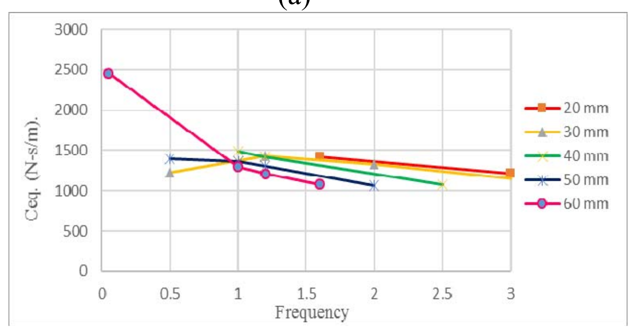
Fig 11: (a), (b) and (c) are Frequency vs Equivalent Damping Coefficient plot for 10 mm, 20mm, and combined for 30mm, 40mm, 50mm, 60mm and 63mm amplitude respectively for (Front Damper). These figures show variation of Equivalent Damping Coefficient with Frequencies and amplitudes.

B. Determination of Equivalent Damping Coefficient for Rear Damper

TABLE IV. EQUIVALENT DAMPING COEFFICIENT REAR DAMPER



(a)



(b)

Fig. 12. (a) and (b) are Frequency vs Equivalent Damping Coefficient plot for 10 mm, 20mm, and combined for 30mm, 40mm, 50mm, 60mm amplitude respectively for (Rear Damper). These figures show variation of Equivalent Damping Coefficient with Frequencies and amplitudes.

C. Discussion on Frequency vs $C_{eq.}$ Plots.

Fig.11:(a), (b) and (c) it is clear that the Equivalent Damping Coefficient is vary in small range of value with slight increasing order towards higher frequency except for very low frequency where sudden increased value is shown. This is because friction damping effect as excitation frequency is very low damping force which is velocity dependent force is negligible and hence the friction force present is predominant and hence in equation (8) while calculating C_{eq} for low frequency the numerator

that is W_d is not changing significantly than that of denominator hence due to very low value of denominator, value of C_{eq}. goes very high. Hence neglecting effect of friction damping and taking in to account value of C_{eq}. for another frequencies and amplitude except low excitation frequency it varies between approximately 1800 N-sec/m to 2200 N-sec/m. similarly, in case of rear damper that is from "Fig.12": (a) and (b) also it is clear that the Equivalent Damping Coefficient is vary in small range of value but in slight decreasing order towards higher frequency. Except for very low frequency where sudden increased value is shown. This is because of friction damping same as stated in case of front damper hence neglecting effect of friction damping and taking in to account value of C_{eq}. For another frequencies and amplitude except low frequency it varies between approximately 800 N-sec/m to 1400 N-sec/m. by taking average of C_{eq} over entire frequency and amplitude except low frequency the approximate value near to 1200 N-sec/m for C_{eq}. can be taken.

V. CONCLUSION

In order to evaluate equivalent damping coefficient of Damper which is an Equivalent linearization of nonlinear system, from which nearer to the same response of nonlinear system is achieved and complexity of nonlinearity can be avoided in analysis. To fulfill the set objectives, the experimental testing is performed on both test specimens. The results got from testing is then analyzed and various plots i.e (T-X),(F-X),(V-F) etc. have drawn in order to verify behavior of both test specimens under set input conditions. Jacobsen's Approach is used to obtained Equivalent Damping Coefficient (C_{eq}.). both Test specimens shows almost constant behavior between selected frequency excepts very low excitation frequency. But Front Damper shows slight increasing nature of C_{eq}. Over increasing frequency whether rear Damper shows slight decreasing nature of C_{eq}. Over increasing frequency. The Approximate value of C_{eq}. Can be estimated by averaging value of C_{eq}. Over selected amplitude and frequency except very low excitation frequency hence for Front Damper it is to be suggested 2000N-s/m as its range varies between 1800N-s/m to 2200N-s/m. and for Rear Damper its 1200N-s/m as its range varies between 800N-s/m to 1400N-s/m.

REFERENCES

[1] J. P. Bandstra, Comparison of Equivalent Viscous Damping and Nonlinear Damping in Discrete and Continuous Vibrating Systems, Journal of Vibration, Acoustics, Stress, and Reliability in Design, Vol. 105, Jul. 1983, pp. 382-392.

[2] Jorg Wallaschek, Dynamics of Non-Linear Automobile Dampers, Int. J. Non-Linear Mechanics, Vol.25 No2/3,1990, pp. 299-308.

[3] Carlos A. B.," Equivalent Viscous Damping Equations for Direct Displacement Based Design" Master Degree Thesis, Dept. Earthquake Engg., Univ. of Pavia, Pavia, Italy, 2004.

[4] Rahul Zaharia, Equivalent Viscous Damping Models in Displacement Based Seismic Design, Bul. Inst. Polit. Lasi, t. LI(LV). F 1-2, 2005, pp. 51-59.

[5] The Damper Handbook, Second Edition, John Wiley & Sons, John C. Dixon, England, 2007, pp. 259-287, 337-357.

[6] H. M. Dwairi, M. J. Kowalsky, and J. M. Nau, Equivalent Damping in Support of Direct Displacement-Based Design, Journal of Earthquake Engineering, Volume11, 2007, pp. 512–530.

[7] M.S.M. Sani, M.M. Rahman, M.M. Noor, K. Kadirgama and M.R.M. Rejab. Study on Dynamic Characteristics of Automotive Damper System, Malaysian Science and Technology Congress [online], Malaysia, 2008, pp. 623-628.

[8] A. M. Salem, W. Galal, Identification of Characteristics of Hydraulic Dampers Used in Light Weight Tracked Vehicles, 13th International Conference on AEROSPACE SCIENCES & AVIATION TECHNOLOGY, 2009, pp.1-13.

[9] Yan Cui, Thomas R. Kurfess, and Michael Messman, Testing and Modeling of Nonlinear Properties of Dampers for Vehicle Dynamics Studies, Proceedings of the World Congress on Engineering and Computer Science, Vol II, 2010, pp.1-6.

[10] Yongjie Lu, Shaohua Li and Na Chen, Research on Damping Characteristics of Shock Absorber for Heavy Vehicle, Research Journal of Applied Sciences, Engineering and Technology, Volume 5(3), 2013, pp. 842-847.