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Test Rig Design for Measurement of Shock Absorber Characteristics

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H. R. Sapramer
Mechanical Engineering Department
Sir Bhavsinhaji Polytechnic Institute
Bhavnagar, India
merhamir@yahoo.com

Dr. G. D. Acharya
Principal
Atmiya Institute of Science and Technology
Rajkot, India
gdacharya@rediffmail.com

Abstract: Shock absorber, an example of under damped vibration system is the key element in the suspension system of any automobile vehicles which aim to absorb a maximum amount of kinetic energy and sometimes potential energy. This paper mainly focuses on the measurement of characteristics of shock absorber. The shock absorber is characterized by its instantaneous value of position, velocity, acceleration, force, pressure, temperature etc and various plots among these parameters. For the measurement of listed parameters of the shock absorber a test rig is designed and developed. An experiment on the test rig is carried out at different speeds and loads which lead to the output in terms of sinusoidal waveform on attached oscilloscope. The waveform is used to find out the characteristics at different load-speed combination. The results obtained are used to find out the behavior of shock absorber at different speed and loads.
Keywords: electromechanical tester; sensors; conceptual design; mathematical design.

I. INTRODUCTION

Driving comfort and maneuverability are the primary design objectives in development of an automobile's shock-isolation system which transmits fewer amounts of vibrations to the person sitting on the vehicle. Shock absorber subjected to the vibratory forces is a necessary component in the vehicle suspension system. It is an example of under damped vibration system; creating the vibrations under the external loading on it. It absorbs some amount of force, motion and transmits remaining amount of force and motion to the person sitting on the vehicle.

According to experiment to produce actual damping condition of shock absorber in room, it is necessary to construct a device which can produce up and down movement of shock absorber. Shock absorber tester is developed for this purpose which is used to collect experimental data.

Attempts have been made previously to find out the various shock absorber properties by various approaches. Rao and Greenberg carried experiment for measurement of equivalent stiffness and damping properties of shock absorber.[1] Y. Ping studied dynamic behavior of an oil-air coupling shock absorber.[2] A K Samantray developed preloading mechanism for liquid spring /damper shock absorber and studied the shock isolation properties.[3] For nonlinear viscous damping device force transmissibility of multi degree of freedom is also studied by Peng and others.[4] Also simulation and experimental validation of vehicle dynamic characteristic for displacement sensitive shock absorber with fluid flow modeling.[5,6]. An extensive work has been done on transmissibility of vibration isolator like SALIM vibration isolator [7], Pneumatic Vibration Isolator [8] which is used in various stationary applications. Yang Ping and other researched on dynamic transmissibility of complex non linear coupling isolator.[9]

From the above literature review it is found that very limited work has been done on the shock absorber test rig, so far as the loading condition is concerned. This research paper presents a model test setup to calculate the characteristics of shock absorber at various loading conditions. The principle mechanism for the basis of this test rig designed to measure the characteristics is single slider crank mechanism. This mechanism converts rotary motion of the circulating disc into the linear motion of the shock absorber. At various loads and speeds combinations the readings on the test rig is taken with the help of various sensors mounting on test rig and by using the data, characteristics of shock absorber is calculated.

Testing of shock absorber may be categorized under two main headings:
(1) Rig testing of part or whole of the shock absorber;
(2) Road testing of the shock absorber on the vehicle;

Rig testing of complete shock absorbers or their separate parts may be placed under three further headings:
(1) To measure performance;
(2) To check durability;
(3) To test theoretical models.

Testing of theory is required to validate methods of analysis and to give confidence in theory for design work. This is likely to involve testing of individual parts or testing of complete shock absorber to relate damping characteristics, to investigate piston or rod seal friction effects, etc.

Performance testing is required to check that prototypes or samples of production dampers meet their specifications within tolerance, and are adequately consistent one to another. In competition, performance testing is required to check that a given valve set-up gives the expected behavior and, again, that dampers are consistent and in matched pairs. Consistency tests and matching tests are frequently disappointing because of the sensitivity of the dampers to small dimensional discrepancies in the valves and to small leakage paths. Adjustable are frequently inconsistent one to another in their response to the adjustment setting. Testing may therefore be used to select matched pairs or to refine manufacture and assembly to the necessary level.

Durability testing is sometimes performed by rig testing, and this can be useful for initial testing of new materials or production methods, but the primary durability testing is by road testing.

Road testing may be divided into four main categories
(1) Long-distance testing of durability on public roads;
(2) short-distance durability testing on severe test roads;
(3) Ride and handling testing on public roads;
(4) Ride and handling testing on special test roads.

Long-distance road testing of dampers alone would generally be uneconomic, but is undertaken in conjunction with reliability testing of all the other parts of complete vehicles. Short-distance severe testing of complete vehicles is sometimes used, driving over pave´ type surfaces or similar. Testing of handling is mainly undertaken on special circuits; for safety reasons, public roads are not generally suitable for extreme cornering testing. Ride testing is of course viable on public roads, but special roads with particular surface conditions obviously offer some advantages. Testing of the complete vehicle may be intended to assess the suitability of proposed dampers for a particular vehicle, or to relate actual vehicle behavior in ride and handling to theoretical predictions in order to validate vehicle dynamics theory for design purposes.

Following are typical plots of interest for shock absorber to characterize it.

- Position vs Time;
- Velocity vs Time;
- Acceleration vs Time;
- Force vs Time;
- Force vs Position;
- Force vs Velocity ;

For obtaining such parameters, test rig should be properly design.

There are three main types of testing methodology adopted according to technology applied and value of damping force.

- Transient Testing
- Electromechanical Testers
- Hydraulic Tester

II. ELECTROMECHANICAL TESTER

Fig. 1 illustrate reciprocating type electromechanical shock absorber fundamental. In electro mechanical tester, cyclic tests are achieved by reciprocating the shock absorber in a roughly sinusoidal manner, with a slider crank mechanisms. The force is measured by load cell holding the other end of the damper.

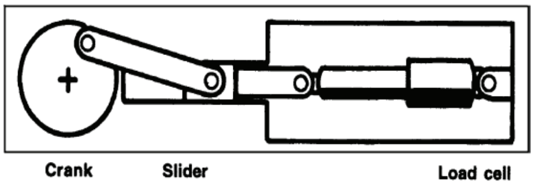

Fig. 1. Reciprocating type electromechanical tester [10]

The inclination of the connecting rod introduces a substantial harmonic into the damper motion, which is therefore quite significantly nonsinusoidal for practical connecting rod lengths. This can be eliminated by using a Scotch Yoke mechanism which gives a true sinusoid, Fig. 2.

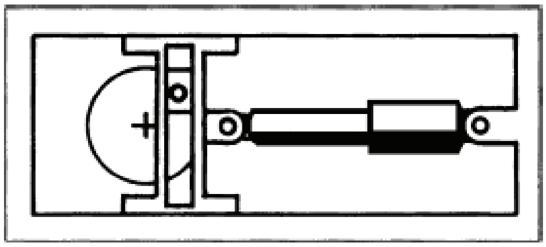

Fig. 2. Scotch Yoke drive [10]

In a cyclic test, the frequency or amplitude is varied to give a desired peak velocity, using

$$X = X_0 \sin(\omega t)$$
$$V = \omega X_0 \cos(\omega t)$$
$$A = -\omega^2 X_0 \sin(\omega t)$$

The velocity amplitude (i.e. amplitude of the sinusoidal velocity graph) is given by

$$V_0 = \omega X_0 = 2\pi f X_0$$

III. DESIGN OF TEST RIG

A) Conceptual Design

Shock absorber test rig is a machine to test shocks and generate graphs for the shock characteristics. These graphs could be printed for the shocks or stored so user could develop a database of how each shock works under the test conditions. This machine replaces the trial and error approach into a reliable and efficient method to determine the shocks used during a race.

Fig. 3 indicates details of shock absorber test rig setup. The setup consist of Piston – crank (Single Slider Crank Mechanism). This mechanism consists of a flywheel (crank), connecting rod, and piston. The flywheels have holes drilled to achieve different stroke lengths, shown in fig.4. The advantage to this mechanism is its cost effectiveness because there is less high tolerance machining. The frequency is adjusted by using Variable frequency drive system based electric motor. The

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output from the motor is geared down, using gearbox. The maximum output shaft speed will be in the range of 300 to 400 RPM at full speed of motor. Variation of stroke will be possible by fixing the connecting road in appropriate hole, made in disk type flywheel, so the stroke is set to give the desired maximum speed, within the limits of the damper and test apparatus. There are ten screwed holes located over spiral shape; connecting rod can be fixed in any hole to select stroke length. The longer the stroke, the greater the power needed on motor to move the shock absorber.

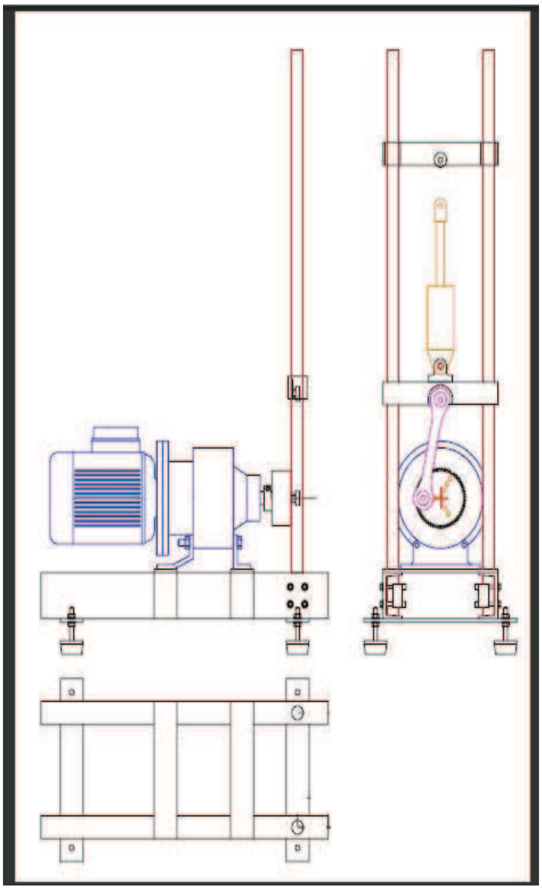

Fig. 3. Setup of Shock Absorber Test Rig

Fig. 4. Disk type Flywheel with stroke adjuster hole. (Real photo)

The experimental set up involves following steps:

- The shaft is driven through a single-phase AC motor.
- The single phase AC motor speed is controlled by Variable Frequency Drive System.
- From AC motor, drive is brought to a gear reducer whose gear reduction ratio 3:1
- From these the shaft is driven at constant rpm.
- As the single slider crank mechanism is connected to the shaft, mechanism rotates from which the rotary motion is converted into reciprocating motion by means of follower.
- The follower is guided by a bush and in order to overcome any distortion, side frames are welded to that.
- The shock absorber, which is subjected to both compressive and tensile force.
- Sensors are used to get output displacement, velocity and acceleration.
- From the value, the performance testing of the shock absorber is derived.

Instrumentation of test setup

The basic parameters to be measured will be including instantaneous values of:

- Position (X)
- Velocity (V)
- Acceleration (A)
- Force (F)
- Pressure (P)
- Temperature (T)

These need sensors, pulse data processing and suitable display. In addition the data stream will be processed to give items such as cyclic extremes of position and force.

1) Oscilloscope

The raw data, change through the cycle, is usually presented on an oscilloscope. The storage type of oscilloscope is much superior in showing the cycle shape, such as force against position; F(X) will be attached with test rig.

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2) Linear Variable Differential Transformer (LVDT).
LVDT is a position sensor, will be built into the RAM. It will give a voltage output directly and linearly related to the position, with a positional signal.

3) Velocity Sensor
Velocity of piston is derived from velocity sensor. Velocity is also obtained by electronic differentiation of the position signal obtained by LVDT.

4) Load cell
The damper force is measured by load cell. It is simply a slightly flexible beam supporting the static end of the damper, giving a small deflection, which can be measured to give an instantaneous load signal.

5) Accelerometer sensor
It gives instantaneous value of acceleration. Acceleration can be also obtained by differentiation of the velocity signal, but two stage of differentiation will greatly exaggerate any noise in the original position signal. Accelerometer sensor is basically just a load cell with a known mass, with acceleration derived from A = F/m. Velocity also could be integrated from the acceleration.

6) Pressure sensor
Damper liquid pressure is measured by pressure sensor. It is installed into damper body by welding or brazing of a tapped boss to accept a standard sensor. It is preferably positioned at the extreme ends of the damper so that the piston seals are not damaged by passing over the hole and so that welding distortion of the working tube does not cause the leakage.

7) Thermocouple sensor
It is used to measure temperature of damper body and damper fluid. The temperature value is affecting the performance, tending to reduce the damping forces at a given speed, required to measure it. The most suitable sensors are thin flexible insulated wires, and should be rated for a temperature up to 2000C or better. These are easily taped to the body of the damper. One at mid stroke is sufficient for basic monitoring.

Mathematical Design

8) Maximum force acting on the roller:
Motor Power = P = 2.0 HP= 1.5 KW
Motor is run at 1440 rpm. The maximum speed available on disk type flywheel shaft is about 450 rpm by reduction gear box so that it can lift the shock absorber and also produces maximum torque.

$P = (2\pi NT) / (60)$ (1)

Where, P = Motor Power , N= r.p.m., T = Torque
Therefore, $(1.5\times10^3) = (2\pi\times450\times T) / (60)$
T= 31.83 Nm
Torque is given as,

$T = F\times R$ (2)

Where, F= Force acting on roller
R = Distance between the centre of hole in plate for required stroke (maximum) to the motor output shaft.
= 0.05 m

Therefore,
31.83 = F × 0.05
F=636 Newton
As total force acting downwards (Weight of the bushes + Max dead weight can be added) = 5+5 = 10 kg= 100 Newton is less than the force acting upwards (636 Newton). So that shock absorber is easily lifted upwards by the disc.

9) Selection of Bearing
The deep groove ball bearing is selected to convert the rotary motion of the disc into the linear motion of the shock absorber. The protruded rod of the disc is fitted into the inner race of the bearing and outer race rotates and converts the rotary motion of the disc into linear motion of the shock absorber simultaneously.
Now from equation 2,
Radial load (Fr) = 636 N, Axial load (Fa) = 0 N
Assuming static load carrying capacity C_0 = 3550
Fa / Fr = 0 & Fa / C_0 = 0
X= Radial factor Y = Axial factor
So taking X = 1 & Y= 0
P = X Fr + Y Fa
Effective load = P =636 N
Assuming bearing life L_h = 8000 Hrs
Life $L = 60\ n\ L_h / 10^6$
$L = 60\times150\times8000 / 10^6 = 72$
$L = (C / P)^3$ for ball bearing
Therefore, $C = (636 \times 72^{1/3}) \times 1.2$
C= 3178 N < 7800 N
So design is safe.
So we selected the bearing no. SKF-6202.

IV. CONCLUSION

Testing of theory is required to validate methods of analysis and to give confidence in theory for design work. This is likely to involve testing of individual parts or testing of complete shock absorber to relate damping characteristics, to investigate piston or rod seal friction effects, etc.

The principle mechanism for the basis of this test rig designed to measure the characteristics is single slider crank mechanism. This mechanism converts rotary motion of the circulating disc into the linear motion of the shock absorber. At various loads and speeds combinations the readings on the test rig is taken with the help of various sensors mounting on test rig and by using the data, characteristics of shock absorber is calculated.

The final accuracy of shock absorbers performance is decided by experimental data collection through shock absorber test rig. Thus the shock absorber test rig design is very important for characteristics of shock absorber. It is done by conceptual and mathematical analysis for force caring capacity by test rig.

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