Design of Vibrational Analysis Test Rig for Springs and Dampers: (Quarter Car Model)

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Abstract: ***In This modern world automobile has become the backbone of the society and many people are showing at most interest towards luxury and comfort. As a result various suspension systems are designed accordingly. Our project is to develop simplified suspension system testing setup. The reduced model of full car is developed (a quarter car) so as to have a simplified and cost effective model and also to reduce the complications in its design and manufacturing. A MacPherson strut suspension is selected as it widely used in most of the passenger car. For this a test rig was built to determine the characteristics of a suspension system, excitation was provided from the bottom and road condition simulation were provided with the help of a cam having cylindrical and semi-cylindrical pipes welded on to the surface of the cam, the cam was run by a motor. MacPherson strut of TATA NANO car was selected for testing. Accelerometer sensors (MPU-6050) were mounted at two different points to record the acceleration over a period of time, the transmissibility was also determined.***

Keywords: MacPherson strut, suspension system, TATA NANO, transmissibility, accelerometer sensors

1. Introduction

An automobile suspension framework is the component that physically isolates the car body from the wheels of the car. The design of the suspension system has been significantly expanded because of expanding vehicle abilities. Different design attributes to be considered with a specific end goal to accomplish a good suspension framework. Suspension comprises of the arrangement of springs, safeguards and linkages that associates a vehicle to its wheels. In other importance, suspension system is a component that physically isolates the car body from the wheel. The principle capacity of vehicle suspension system is to minimize the vertical acceleration that is transmitted to the passenger which there by provides comfort.

Spring and damper are constant parameters that directly affect road holding and ride comfort. If the system is heavily damped it throws the vehicle on unevenness of road. If the system is lightly damped it reduces the stability of vehicle in turns.

In this paper we developed a quarter car models and analysis is done. In this paper we compared two different types of springs and concluded the best suspension among them.

2. Literature Review

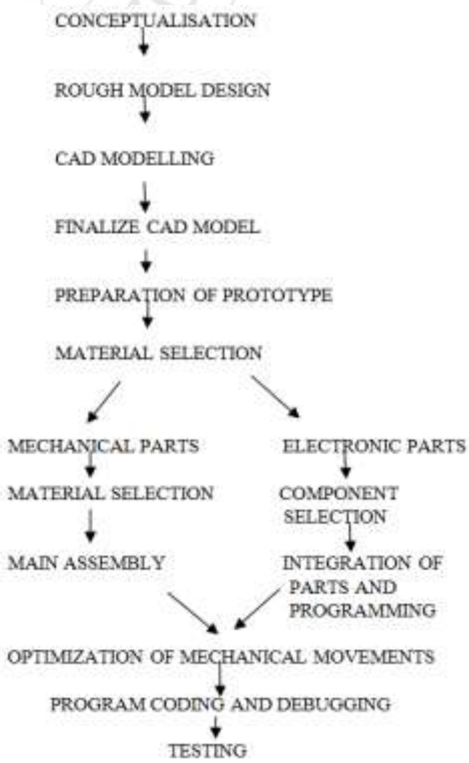
Yogesh Sanjay Pathare [1] studied both analytical and experimental results for a McPherson strut suspension system and compared the analytical results with experimental. Initially mathematical model was developed and results were taken in MATLAB 10 as an analytical solver and in later stages an experimental model is done and actual readings were taken for various inputs and thereby compared the analytical values with the experimental values for the reliability of the setup.

Trupti P. Phalke [2] studied the performance of passive suspension model is compared with semi-active suspension system for different velocities and road inputs

3. Objective

The main objective of this project is to develop a indoor vehicle suspension simulation test rig. To record the input and output acceleration over a period of time and finding transmissibility

4. Methodology



5. Design and working of mechanical parts

CAD DESIGN

WORKING

- A single phase AC motor drives a pulley mounted on a solid shaft through a belt drive.
- A cam having cylindrical and semi-cylindrical pipes welded on its surface is welded to the same solid shaft.
- The wheel assembly along with the suspension is mounted on the cam and held in the position.
- Due to the variations in the height of the semi-cylindrical and cylindrical pipes, the wheel assembly will have a linear motion, which in turn provides a linear motion to the spring-damper assembly.
- Accelerometer sensors are mounted at two different positions so as to record accelerations over a period of time.

6. Design Calculations

Motor-single phase 1.5HP motor,
Diameter of driving pulley d=0.075m (3"),
Diameter of driven pulley D=0.225m (9"),
Diameter of shaft =d_s in m,
Torque on shaft = M_{ts} in N-m,
Torque of Motor=M_{tm} in N-m,
θ_l=angle of contact on larger pulley in rad,
θ_s=angle of contact on smaller pulley in rad,
C=centre distance in m,
L=length of belt in m,
T_1=Tension of belt on tight side in N,
T_2=Tension of belt on slack side in N,
T_c=Centrifugal force on belt in N,
w=weight density of belt material=10.89×10^3 Nm^{-3},
width of belt=b in m,
thickness of belt=t in m,
μ=coefficient of friction between belt and pulley,
μ_1=apparent coefficient of friction,
α=groove angle of pulley degree,
C_m, C_t,-the numerical combined shock and fatigue factors to be applied to the computed bending moment and torsional moment respectively
τ_{max}=torsional shear stress Nm^{-2}

Mass distribution in rear engine vehicles is 35:65
Kerb weight of TATO Nano car is 600Kg, therefore weight acting on the front part is
=0.35×600
=210Kg
Therefore weight on each wheel =210/2
=105Kg
Total load acting downwards on shaft=105sin75+26+23+3
=153.42Kg
Torque acting on shaft=Force × (radius of cam + difference in bump height)
M_{ts} = (153.42×9.81) ×0.21
=316.06N-m
Torque on shaft is same, therefore torque on pulley=316.06N-m

$$\frac{M_{ts}}{M_{tp}} = \frac{D}{d}$$

$$\frac{316.06}{M_{tp}} = \frac{0.225}{0.075}$$

M_{tp}=105.35N-m

$$P = \frac{2\pi N M_{tp}}{60}$$

$$1119 = \frac{2\pi\times N\times105.35}{60}$$

N=101.43 rpm (motor starting rpm)

Belt calculation

$$v = \frac{\pi dN}{60}$$

$$v = \frac{\pi\times0.075\times1450}{60}$$

$v = 5.7 ms^{-1}$
$C = (0.07\ to\ 0.1)v$
$C = 0.085v$
$C = 0.491$m

Angle of contact in the open belt drive

a) On smaller pulley

$$\theta_s=\pi-2\sin^{-1}\left(\frac{D-d}{2C}\right)$$

$$\theta_s=\pi-2\sin^{-1}\left(\frac{0.225-0.075}{2\times0.491}\right)$$

θ_s=162.4° or 2.83rad

b) On larger pulley

$$\theta_l=\pi+2\sin^{-1}\left(\frac{D-d}{2C}\right)$$

$$\theta_l=\pi+2\sin^{-1}\left(\frac{0.225-0.75}{2\times0.491}\right)$$

θ_l=197.5° or 3.44rad

Length of belt, $L=2C+\frac{\pi}{2}(D+d)+\frac{(D-d)^2}{4C}$

$$L = (2\times0.491) + \left(\frac{\pi(0.225+0.075)}{2}\right) + \frac{(0.225-0.075)^2}{4\times0.0491}$$

$L = 1.46$m

For transmission of 1.1 KW power and belt speed $5.7ms^{-1}$ 'B' belt is selected
b=0.017m, t=0.011m

$$\frac{T_1-T_c}{T_2-T_c} = e^{\mu_1\theta_s}$$

$$T_c = \frac{wbtv^2}{10^6 g} \quad g=9.8ms^{-1}$$

$$T_c = \frac{10.89\times10^3\times17\times10^{-3}\times5.78^2}{9.81\times10^6}$$

$T_c = 6.93\times10^{-6}$N

By Barth's formula

$$\mu = 0.54 - \frac{0.712}{2.542+v}$$

$\mu = 0.45$

$$\mu_1 = \frac{\mu}{\sin(\frac{\alpha}{2})}$$

$$\mu_1 = \frac{0.45}{\sin17}$$

$\mu_1 = 1.53$

$\frac{T_1 - 6.93\times10^{-6}}{T_2 - 6.93\times10^{-6}} = e^{\mu_1 \theta_s}$

$T_1 - 6.93 \times 10^{-6} = (T_2 - 6.93 \times 10^{-6}) \times 77.89$

$T_1 = 77.82T_2 + 5.46 \times 10^{-4}$

$M_{ts} = (T_1 - T_2)R$

$316.06 = (77.89T_2 + 5.46 \times 10^{-4} - T_2) \times 0.1125$

$T_2 = 36.5$N

$\therefore T_1 = 2845.32$N

Vertical Load diagram

Taking moments about A

$R_{DV} \times 0.62 = (150.4 \times 9.81 \times 0.23) + (3 \times 9.81 \times 0.42)$

$R_{DV} = 567.27$N

$R_{AV} + R_{DV} = (146.17 \times 9.81) + (3 \times 9.81)$

$\therefore R_{AV}$ =937.58N

Vertical Bending Moment

Bending moment at A=0

Bending moment at B=937.58×0.23
=215.64N-m

Bending moment at C=567.27×0.2
=113.45N-m

Bending moment at D=0

Horizontal Load diagram

Taking moments about A

$R_{DH} \times 0.62 = (2845.32 + 36.6) \times 0.42$

$R_{DH} = 1952.2$N

$R_{DH} + R_{AH} = 2881.92$

$\therefore R_{AH} = 929.72$N

Horizontal Bending Moment Diagram

Bending moment at A=0

Bending Moment at B=929.72×0.23
= 213.83N-m

Bending Moment at C=1952.2×0.2
=390.44N-m

Bending Moment at D=0

Resultant Bending Moment

Bending Moment at A=0

Bending Moment at B=$\sqrt{213.82^2 + 215.64^2}$
=303.67N-m

Bending Moment at C=$\sqrt{390.44^2 + 113.45^2}$
=406.58N-m

Select maximum bending moment $M_b = 406.58$N-m

Maximum Torque $M_{ts} = M_t = 316.06$N-m

Assume shaft material to be of Mild Steel EN8

$\sigma_u = 700\ to\ 850\ Mpa$

$\sigma_u = 775 \times 10^6$Nm^{-2}

$\sigma_y = 465 \times 10^6$Nm^{-2}

According to ASME code of standard

$\tau_{max} = 0.3\sigma_y$

=139.5×10^6 Nm^{-2}

$\tau_{max} = 0.18\sigma_u$

=139.5×10^6 Nm^{-2}

Select least $\tau_{max} = 139.5\times10^6$ Nm^{-2}

Steady or gradually applied loads for rotating shafts,
C_m=1.5, C_t=1

ASME code for design of transmission shafting,

According to maximum shear stress theory,

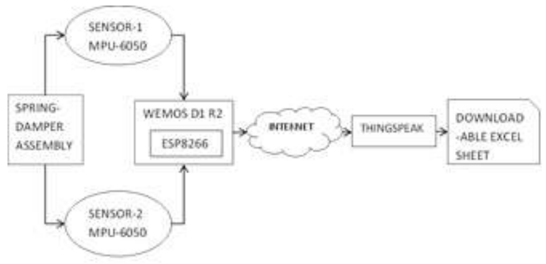
$$d_s = \sqrt[3]{\frac{16}{\pi\tau_{max}}\sqrt{(C_m M_b)^2 + (C_t M_t)^2}}$$

$$d_s = \sqrt[3]{\frac{16}{\pi\times139.5\times10^6}\sqrt{(1.5 \times 406.58)^2 + (1 \times 316.06)^2}}$$

$d_s = 0.02927$ m

Standard diameter of shaft, $d_s = 32$ mm

7. Working of Electronic parts



MPU6050:

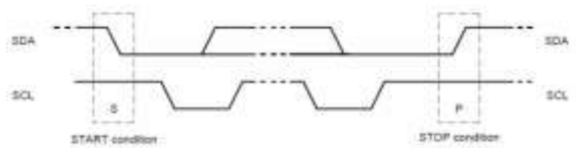
The InvenSense MPU-6050 sensor contains a MEMS accelerometer and a MEMS gyro in a single chip. It is very accurate, as it contains 16-bits analog to digital conversion hardware for each channel. Therefore it captures the x, y, and z channel at the same time.

For precision tracking of both fast and slow motions, the parts feature a user-programmable gyro full-scale range of ±250, ±500, ±1000, and ±2000 °/sec (dps), and a user-programmable accelerometer full-scale range of ±2g, ±4g, ±8g, and ±16g. Additional features include an embedded temperature sensor and an on-chip oscillator with ±1% variation over the operating temperature range.

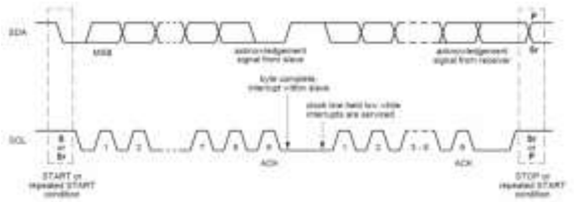
The sensor uses the I2C-bus for communication.

I2C BUS PROTOCOL: The I2C bus physically consists of 2 active wires and a ground connection. The active wires, called SDA and SCL, are both bi-directional. SDA is the Serial Data line, and SCL is the Serial Clock line. Every device hooked up to the bus has its own unique address. The I2C bus is a multi-master bus. This means that more than one IC capable of initiating a data transfer can be connected to it. The I2C protocol specification states that the IC that initiates a data transfer on the bus is considered the Bus Master. Consequently, at that time, all the other ICs are regarded to be Bus Slaves. The bus masters are generally microcontrollers.

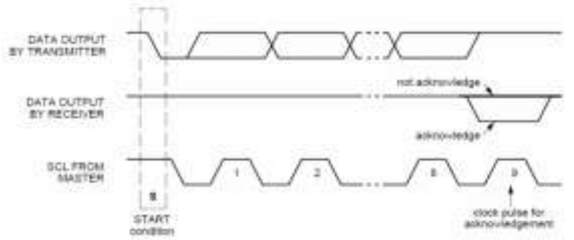
Start and Stop Condition Each I2C command initiated by master device starts with a **START condition** and ends with a **STOP condition**. For both conditions SCL has to be high. A high to low transition of SDA is considered as **START** and a low to high transition as **STOP**.



A.I2C Data Transfer



Data on the I2C bus is transferred in 8-bit packets (bytes) and must be followed by an Acknowledge bit. This bit signals whether the device is ready to proceed with the next byte.



The pin "AD0" selects between I2C address 0x68 and 0x69. That makes it possible to have two of these MPU-6050s in a project. Connect AD0 to GND or 3.3V for the two I2C address.

Calibration of the MPU-6050: The first step is to work out the offset errors and remove them before processing the data. Offsets are caused by a number of factors such as mechanical assembly, mounting, package damage and temperature fluctuations.

To find the offsets we place the sensor perfectly horizontal on a surface and measure the average acceleration/angle in the X, Y and Z axis over 10-20 samples. The values should be 0G in the X and Y axis and will be 1G in the Z axis. Anything over 0G in the X and Y and 1G in Z will be our offsets and the sensors are calibrated to these offset values.

Reading the raw values: The MPU-6050 contains a 1024 byte FIFO buffer. The sensor values are programmed to be placed in the FIFO buffer and it can be read by the Arduino. The FIFO buffer is used together with the interrupt signal. If the MPU-6050 places data in the FIFO buffer, it signals the Arduino with the interrupt signal so the Arduino knows that there is data in the FIFO buffer waiting to be read.

One MPU-6050 is placed before the suspension to measure the input acceleration and the other is placed just below the load to measure the output acceleration on the spring-damper assembly.

Working: The Fast mode operation of the MPU6050 is setup. The operating frequency is 400 kHz. It is calculated that the acceleration is measured once every 15 milliseconds. The accelerometer full-scale range is set to be 8g.The motor is switched ON and after the load is applied acceleration values on the y-axis are measured. The WeMo's D1 R2 board is used as the microcontroller as it is Arduino compatible as well as it has a built in Wi-Fi module, the esp8266. The **ESP8266** is a low-cost Wi-Fi chip with full **TCP/IP stack and MCU (microcontroller unit) capability** The recorded values are then sent wirelessly, through Wi-Fi to Thingspeak.

Thingspeak: ThingSpeak is a platform providing various services exclusively targeted for building IoT applications. It offers the capabilities of real-time data collection, visualizing the collected data in the form of charts, ability to create plugins and apps for collaborating with web services, social network and other APIs. The core element of ThingSpeak is a 'ThingSpeak Channel'. A channel stores the data that we send to ThingSpeak .To use ThingSpeak, one must sign up and create a channel. Once we have a channel, we can send the data, allowing ThingSpeak to process it and also retrieve the same. It is limited to receiving data once every 15 seconds only. The acceleration versus time graph is obtained from Thingspeak along with the downloadable sensor data in excel format.

8. Figures

Figure 1: TEST RIG

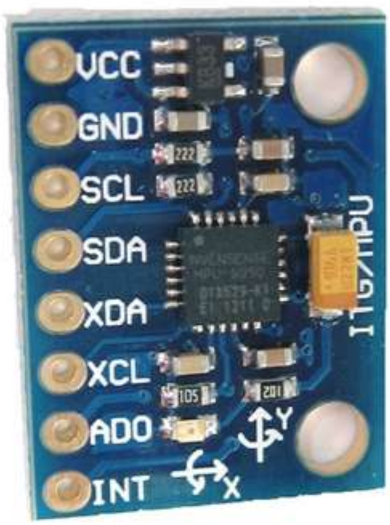
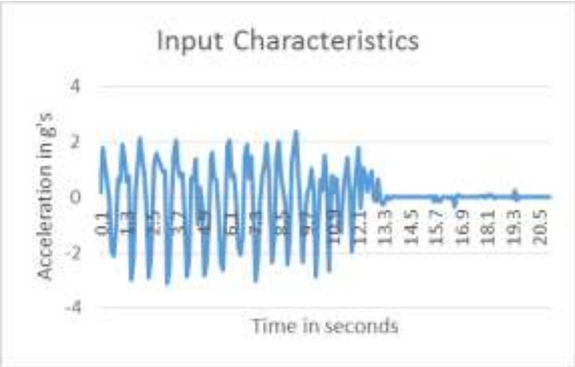
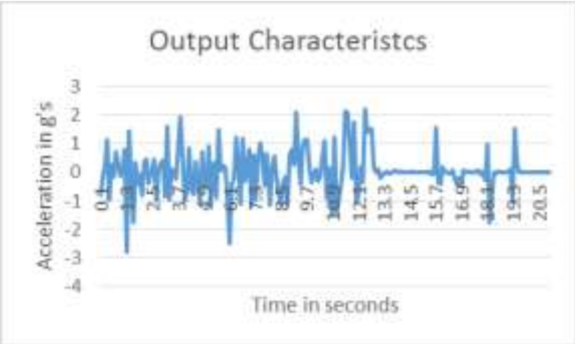


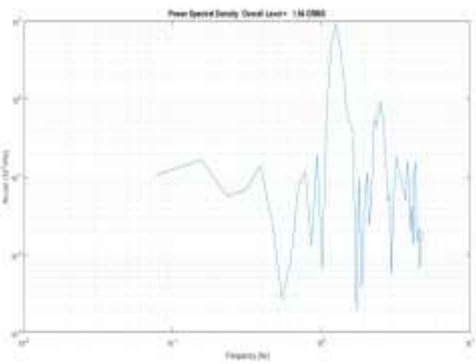
Figure 2: MPU-6050 GY-521 breakout board

9. Results and Discussions

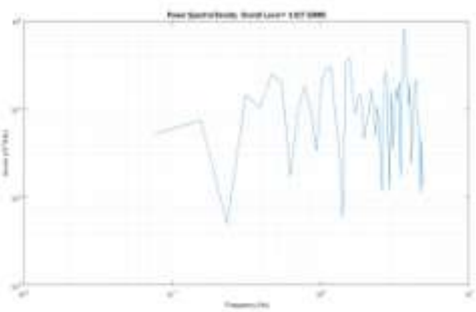




	Maximum value	Minimum Value
Input acceleration in g's	2.38	-3.09
Ouput acceleration in g's	2.13	-2.77



INPUT PSD



OUTPUT PSD

PSD Overall Level (input) =1.54GRMS

PSD Overall Level (output) =0.837GRMS

The Transmissibility was found to be=0.3162, which means that only 31.62% of the force is being transmitted or 68.37% of isolation is obtained.

10. Acknowledgement

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