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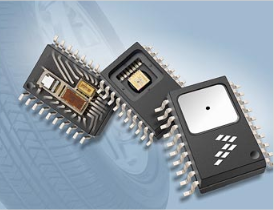
School of Engineering

Department of Mechanical Engineering

in Collaboration with

Center for Advanced Automotive Technology

Accelerometers in Automotive Control



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## Objective

1. Understand the construction of a MEMS accelerometer
2. Understand an example of acceleration control in an automotive mass distribution system

### Accelerometer Description

##### 1.1 Accelerometer Overview

Accelerometers are needed for measurement of a vehicle’s lateral, longitudinal, and vertical accelerations. Modern accelerometers are often small micro electro-mechanical systems (MEMS), and are indeed the simplest MEMS devices possible, consisting of little more than a cantilever beam with a proof mass (also known as seismic mass) [1]. The MEMS accelerometer (Fig. 1) is used in automotive electronics for applications in which acceleration feedback is needed, such as electronic stability control [2].

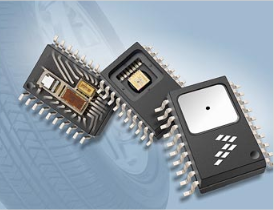


Figure : MEMS Accelerometer [2]

The concept is of a plate attached to flexible beams which deflect due to inertial forces in acceleration [1]. Conceptually, an accelerometer behaves as a damped mass on a spring. When the accelerometer experiences an external force such as gravity, the mass is displaced until the external force is balanced by the spring force. Damping results from the residual gas sealed in the device. Under the influence of external accelerations, the proof mass deflects from its neutral position [3]. This deflection is measured in an analog or digital manner to translate the displacement into acceleration. Most commonly, the capacitance between a set of fixed beams and a set of beams attached to the proof mass is measured. This method is simple, reliable, and inexpensive.

##### 1.2 MEMS Accelerometer Function

Figure 2 is a diagram of a MEMS capacitive accelerometer.



Figure 2: Capacitive mems device [4]

The structure of the accelerometer is as follows: and are flexible beams connected to a movable plate, . and are fixed plates which cannot move. and are the capacitances measured between the movable plate and a fixed plate or . When the system experiences an acceleration, plate is able to move since beams and are flexible and allowed to deflect. The motion of plate changes the distance between it and fixed plates and . The equation for electrical capacitance is [4]

(1)

where is the permittivity of a vacuum, is the relative dielectric constant (a property of the material), is the overlapping area of the plates, and is the air gap between plates. From Equation (1), capacitance depends on the distance between the plates. When no motion has occurred, the capacitances and are equal and are at an initial value, . When the moveable plate is moved closer to plate or by the acceleration, the capacitances and will also change by a value . A measuring circuit detects changes in and which occur during acceleration. The beams are created from micro-machined silicon structures anchored to the substrate in a few points and free to move along the axis of the measured acceleration [2].

### Automotive Acceleration Control Example

##### 2.1 Problem Overview

The following scenario demonstrates the application of an accelerometer in an automotive control system. Given a ground vehicle with two axles speeding up on an even surface, the functional link between the vehicle’s speed and acceleration maintained during the acceleration period is

(2)

where is the constant speed the vehicle reaches at the end of the acceleration and is the maximum acceleration possible.

The required task is to use a mechatronic system to keep the normal loads of the front and rear wheels equal by moving a weight along the longitudinal axis of the vehicle. The appropriate mass of the moving weight, its height coordinate, and travel length are to be determined.

The specifications of the vehicle are given in Tab. 1.

Table : Vehicle Specifications

|  |  |
| --- | --- |
| Total Vehicle Mass, | 500 kg |
| Wheelbase, | 2.5 m |
| Vehicle CG height, | 1.2 m |
| CG Longitudinal Coordinate, | 1.25 m |
| Initial speed, | 0 m/sec |
| Required constant speed, | 5.0 m/sec |
| Maximum acceleration, | 1 m/sec2 |
| Constant, | 0.618 |
| Constant, | 0.785 |
| Front and rear suspension stiffness, | 200,000 N/m |

Figure 3 shows a diagram of the system. The moving weight has mass while the vehicle’s mass is . The location of the vehicle’s center of gravity is labeled as CG is located at the coordinates and . and are the front and rear axle loads.

Assumptions

1. Let the initial position of the moving mass be on top of the front wheel and it should reach the CG by the time vehicle attains the constant maximum speed.
2. The relative acceleration of the moving mass is neglected.
3. Let ‘m’ be the moving mass and ‘h1’ be the CG height of the moving mass.

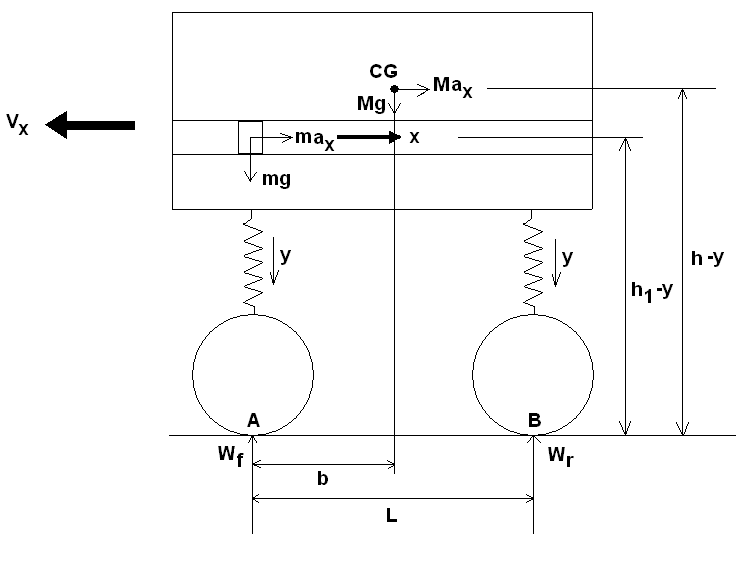
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Figure : Diagram of Vehicle Forces and Dimensions

##### 2.2 Determination of the deflection ‘y’

As the reactions on both the wheels are to be made equal, the total load on each wheel will be half of the total weights involved in the given system. Hence,

(3)

Deflection can be found by dividing weight by the stiffness .

(4)

##### 2.3 Determination of the horizontal position of the moving mass ‘x’

Referring to the free body diagram shown in Fig. (1), two equations can be formed by solving for the moments at points A and B under the front and rear tires.

(5) (6)

From Eq. (3), Eq. (4) and , we get

(7)

(8)

As seen from Eq. (8) the required position of the moving mass is a function of the vehicle acceleration. Hence, by monitoring the vehicle acceleration it is possible to decide the position of the mass using Eq. (8) that will ensure that the reaction on both the wheels are equal to the one defined by Eq. (1).

##### 2.4 Determination of the moving mass ‘m’

For further simplicity of the problem, two assumptions are made:

1. The CG of the vehicle is at the center (i.e. ).
2. The CG height of the moving mass is equal to the CG height of the vehicle (i.e. ).

With the above assumptions, Equations (3), (4) and (5) reduce to

(9)

(10)

(11)

Since at , , hence Eq. (11) becomes

(12)

From solving Eq. (4) and Eq. (12),

(13)

Equation (13) can be solved for different values of moving mass ‘m’. The value of ‘m’ that will give will correspond to the required value of the moving mass ‘m’.

### Computer Model

##### 3.1 Block Diagram of the System

The equations developed in Section 2 are sufficient to define a mathematical model of the system. First, define four gains as

(14)

(15)

(16)

(17)

Equations (9), (10) and (11) can now be reduced to

(18)

(19)

(20)

Eq. (18) and (19) represents the ‘Plant’ while Eq. (20) is the logic for computing the required position of the moving mass that will give equal reactions at both the wheels. They can be represented in a block diagram as shown in Fig. (4).

As shown in Fig. (4), the required position of the moving mass is computed by the controller-1 and fed to the actuator which then moves the mass to the said position.

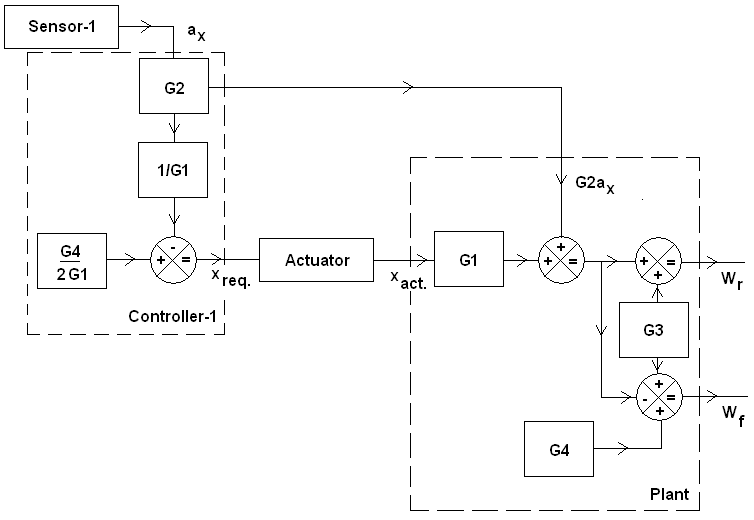


Figure : Control System Block Diagram

##### 3.2 LabVIEW Computer Model

A LabVIEW model implements a block diagram of the mass distribution system. LabVIEW models consist of a block diagram and a front panel. The block diagram contains a graphical representation of the equations which make up the system. The front panel contains controls and indicators which allow the user to manipulate and view the results of the model. Pressing control+e swaps the view between the front panel and block diagram.

Fig. 5 shows the front panel of the model. Here, the numeric controls (A) allow the values of the model parameters to be changed. Pressing the run button (B) will run the model, and show the output values in the charts (C). The stop button (D) will end the run. Numeric indicators (E) show exact values of the gains and wheel reactions.

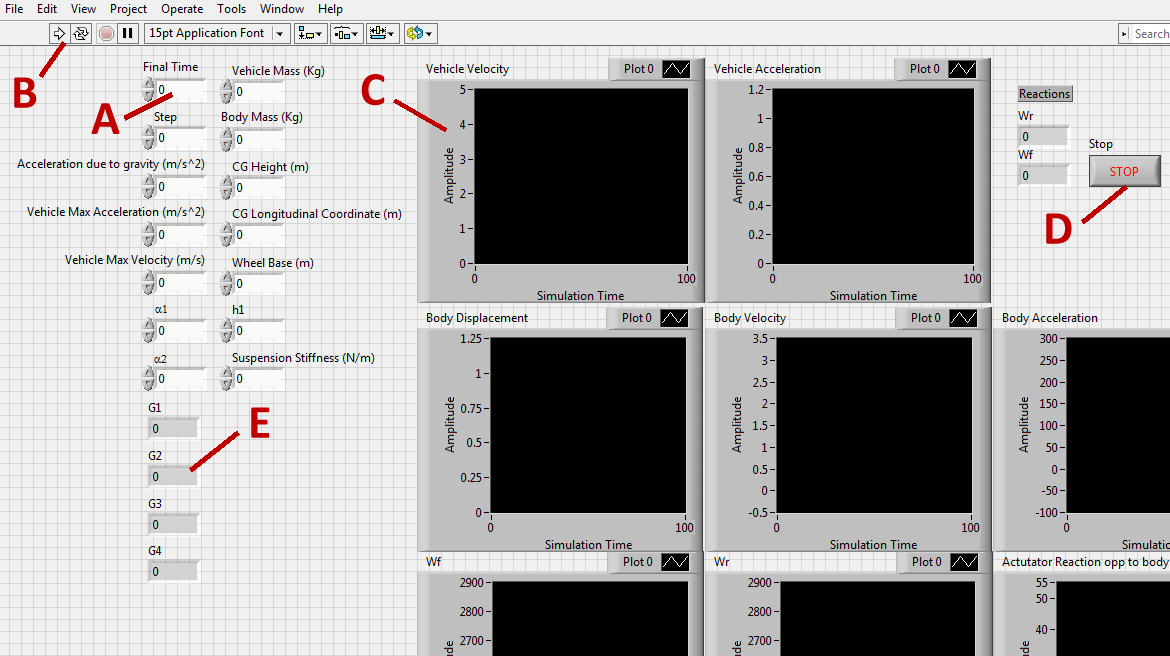


Figure : LabVIEW front panel

Every control and indicator on the front panel has a corresponding element on the block diagram. The block diagram view will show how these controls and indicators are connected. One the block diagram view, one component is the script block shown in Fig. 6.

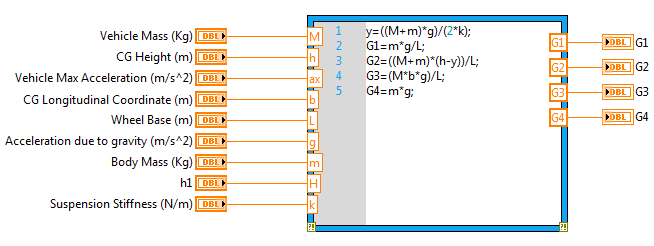


Figure : Script block for calculating gains

The script block allows calculations to be entered as typed equations. Inputs to the script block are on the left. These inputs are model parameters corresponding to the controls on the front panel. These controls are wired to the script block and are used to calculated G1 – G4. These gains are then output to the indicators on the right side. The second aspect of the block diagram is a control and simulation loop (Fig. 7). This block runs a simulation of the diagram inside its borders using the step time and final time input at the left of the model (A). The code in panel (B) implements Equation (2). This calculates the acceleration of the vehicle, and therefore represents the output of a virtual accelerometer. Blocks (C) are variable blocks. They take the value of another indicator in the model. Here, they are used to get the values of gains G1-G4 for calculations. Blocks (D) are mathematical operators performing addition, subtraction, and other operations on its inputs. Block (E) is a summation block which outputs the sum of its inputs. Block (F) is a gain which multiplies the input by a value entered at the top of the block. Block (G) is an integrator while (H) takes a derivative. Block (I) outputs the value to a chart on the front panel.

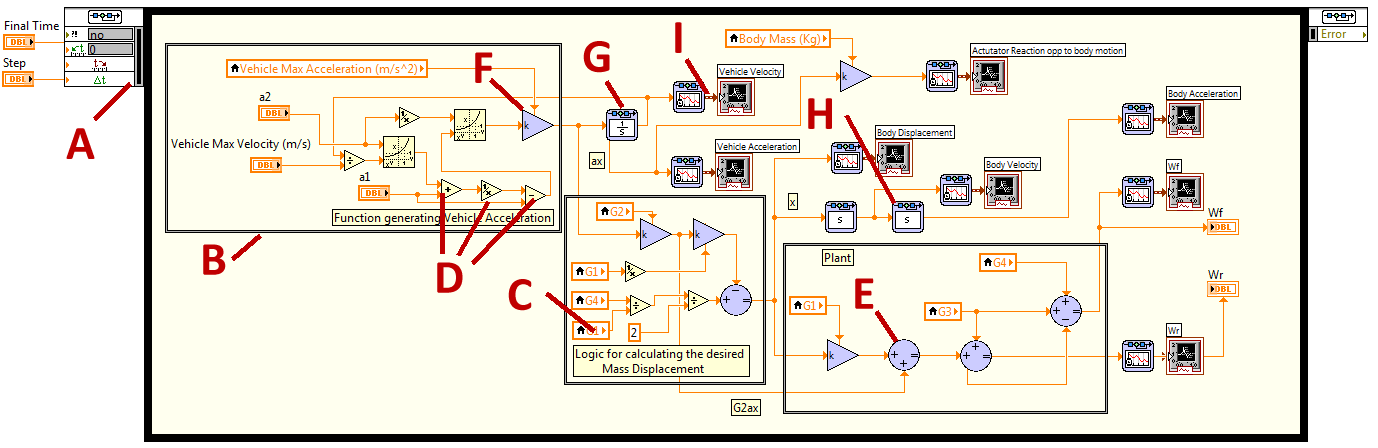


Figure : LabVIEW Block Diagram

To add blocks or controls to the model, right-click on any empty space to bring up the functions or controls window (Fig. 8). Functions are placed on the block diagram and controls (or indicators) on the front panel. Left-click on a terminal of any block to draw a wire to another block. This makes the output of the first block into the input of the second block.

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  | A | B |

Figure 8: LabVIEW Functions (A) and Controls (B)

# References

[1] Thomas, G, “Mechatronic System for Vehicle Weight Distribution Control”, Lawrence Technological University, 2009.

[2] NXP, “MEMS Technology, 2015. <<http://cache.nxp.com/assets/documents/data/en/fact-sheets/MEMSFS.pdf?fsrch=1&sr=1&pageNum=1>>

[3] STMicroelectronics, "LIS244AL MEMS motion sensor: 2-axis - ±2g ultracompact linear accelerometer", 2007.

<<http://www.st.com/stonline/products/literature/ds/13664.pdf>>

[4] Benmessaoud, M., and Nasreddine, M.M., "Optimization of MEMS Capacitive Accelerometer", *Microsystem Technologies*, Volume 19, Issue 5, pp 713-720.

## Assignment:

The LabVIEW \*.vi file contains the model of the mass distribution system. Refer to Section 3 for the operation of the computer model and Section 2 for the modeling equations of the system. The output of the virtual accelerometer is calculated with Eq. (2). Values of the model parameters may be changed on the front panel while the simulation is running, giving an instant update to the system output.

1. Using the given vehicle parameters and equations, calculate the correct value of mass .
2. Using the mass from (1) and vehicle parameters, determine the values of gains and final values of and at the end of the 100 sec simulation.