Measuring a Centre of Gravity of an Object using 4 Load Transducer Method

Sandip G. Patel
Assistant Professor, Mechanical Engg. Department
Chhotubhai Gopalbhai Patel Institute of Technology
Bardoli, Surat, Gujarat, India

Jainish J. Topiwala
Assistant Professor, Mechanical Engg. Department
Chhotubhai Gopalbhai Patel Institute of Technology
Bardoli, Surat, Gujarat, India

***Abstract*—The aim of this study is to investigate the three dimensional centre of gravity of any symmetric or asymmetric object using equipment. This equipment is capable for measuring weight and centre of gravity in a single setup. Instrument measure a weight of any object using a load cell of 1 Ton (2 nos.) and 3 Ton (2 nos.) capacity and coordinates of three axes are measured using calculus. Among three, two axes are measured using a reaction type two axis centre of gravity instrument and then third axes are measured by tilting a mounting surface of the machine. By using force restoration technology and flexure pivots, centre of gravity measurement accuracy is up to 10 millimeters.**

Keywords—Centre of gravity, load cell, force restoration, flexure pivots.

I. INTRODUCTION

The concept of a centre of gravity was first introduced by Archimedes of Syracuse. He worked with simplified assumptions about gravity that amount to a uniform field, thus arriving at the mathematical properties of what we now call the “centre of mass”. The terms "centre of mass" and "centre of gravity" are used synonymously in a uniform gravity field to represent the unique point in an object or system which can be used to describe the system's response to external forces and torques. So, we can say centre of gravity is a point at which all of the weight (or mass) of an object appears to be concentrated. Centre of gravity of regular geometries such as square, rectangle plane and circle are always located at the centre of geometry. Now for complex shapes like human body, the COG will be at naval (or umbilical).

Let’s take an example of an automobile vehicle made from the different component like engine, suspension, frame, chassis, steering mechanism, and transmission line. In the designing of all these components, few of the vehicle parameters are important for variety of purposes such as the centre of gravity (COG) of the vehicle. The COG of a vehicle is rarely provided by the automobile manufacturers. The estimation process needs some knowledge of the COG to have a correct bias for gyroscope measurement [3]. The COG location is important considering the passenger and load distribution. The location is difficult to be estimated because the COG positions changes when the weight on the vehicle changes. Vehicles that have higher COG are more tends to rollover accidents [4]. The COG of vehicle is important to be calculated for producing vehicle in automobile industries for the safety of the user and the public traffic [5].

The COG of an automobile is traditionally determined by placing scales or load cell platforms under the wheels of the vehicle and calculating the CG location from the difference in force measurement at these four points. All the COG measuring setup are work on same principle. There are multiples method for determining COG of object like: Traditional multiple point weighing method (or Reaction method), Improved method of measuring COG with 3 Transducer, COG Measure with 2 moment transducers, COG method using 4 Load Transducers. In this paper we are discussed only COG measuring using 4 load transducer in next section [2].

II. COG MEASURING USING 4 LOAD TRANSDUCER (OR METHODOLOGY)

Traditional multiple point weighting method having limitation due to dynamic range of load cells, so that these instruments were not suitable for projectile and missile measurements but still it is used because of fast and easy to use. Improve method of measuring COG with 3 transducers is fulfil the all drawback of previous method but levelling the machine is difficult and skill operator is required for levelling process. Hence, the implementation of this method is quite difficult. So, one of the good method for determining the COG of object is 4 load transducer method, which is carried out in two stage.

Locating the centre of gravity of a vehicle is important for anticipating the vehicle’s behaviour in different situations. The easiest way to find the lateral and longitudinal coordinates of the centre of gravity is to place the vehicle on four individual level scales. First, the track and the wheelbase of the vehicle are recorded. Then the weight at each wheel is recorded. The weight from each wheel and geometry are used in moment calculations to find the centre of gravity in the longitudinal and lateral equations but difficult is to measure height.

A. *Calculation of C.O.G in X-Y direction*

The longitudinal and lateral centre of gravity positions of an object can be determined by knowing the effective normal forces of the object at each corner. This method is used as the simplest method to find the lateral and longitudinal centre of gravity of any object. It assumes the object is completely static while the forces are measured. Any movement would create dynamic forces that would significantly impact the accuracy of the test.

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Figure 1 shows the force diagram of a stationary object. F_1, F_2, F_3, F_4 are the normal forces at each corners of the platform, x and y relate to the COG, coordinates of the object, and L and T are the length and width of the object. Static force and moment equations can be used to find the centre of gravity coordinates independently of each other.

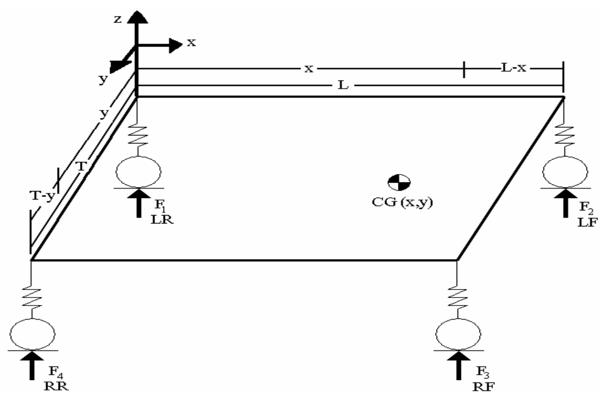

Fig. 1. 4 load transducer method for COG [1]

Taking moment about the imaginary COG point we get,

$$x = \frac{(F_2 + F_3)L}{(F_1 + F_2 + F_3 + F_4)} \tag{1}$$

$$y = \frac{(F_3 + F_4)T}{(F_1 + F_2 + F_3 + F_4)} \tag{2}$$

Equation (1) and (2) is used to find the longitudinal and lateral centre of gravity positions of a object. The vertical CG position is found through other methods such discussed later. From the above derivation, it is clear that the lateral CG equation is nearly identical with the longitudinal CG equation. The differences between the two equations are the two different forces and the multiplication by different lengths in the numerator. The reasons for the differences in the equations are strictly due to the geometry of the object.

B. Calculation of height of centre of gravity (Z direction)

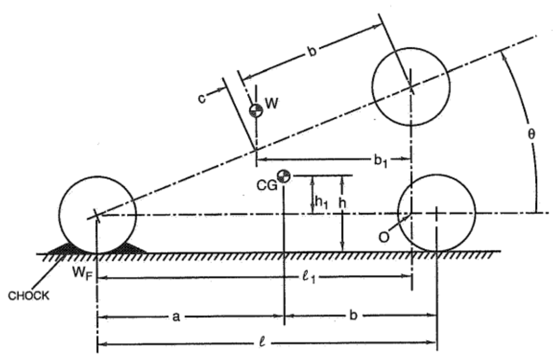

Fig. 2. Tilting of vehicle [1]

The most difficult centre of gravity coordinates to attain in a vehicle is the height. There are multiple methods to attain this parameter, one of which, is to lift the rear axle of the vehicle so the front to rear wheel centre line creates a certain angle with the horizontal.

Height of the centre of gravity is obtained by:

$$h = R_L + \left(\frac{W_F l - Wb}{W \tan \theta} \right) \tag{3}$$

II. INTRODUCTION TO INSTRUMENT

Now a days COG is measured by using software's like CREO, SOLIDWORKS, AUTOCAD etc., but even modern software having some limitation like a position of components such as cables cannot be accurately determined by software. The way cables are actually routed inside the object can shift its centre of gravity by a significant amount. If we are taking about automobile, software considered piston-cylinder assembly as a rectangle shape which is idle shape not the exact shape. So, there is some error in location of centre of gravity. This error can be deducted with the help of the instrument which is measure the actual centre of gravity of automobile. Instrument mainly consist Load cell (Cut type with 3 Ton capacity and shear beam type with 1 Ton capacity), Platform, Structure, Wooden ply, Hydraulic or screw jack, FRC wire, Man code wire, Circuit(MRB), Switches, Transformer, Digital display and LED.

Overall dimension of platform is:

1. C channel size: 75 x 40 x 4 mm
2. L angle: 50 x 50 x 5 mm
3. Metal plate:
   - i. 150 x 200 x 8 mm (4 nos.)
   - ii. 150 x 200 x 15 mm (2 nos.)
   - iii. 250 x 250 x 8 mm (2 nos.)
4. Length : 2130 mm
5. Width : 2150 mm
6. Wooden piece:
   - i. 8'x2' ply (19 mm) (2 nos.)
   - ii. 150 x 200 x 15 mm (4 nos.)
   - iii. 250 x 250 x 8 mm (8 nos.)

For calibration of instrument, we can compare the experimental result with numerical value using a platform. Here we can model a platform in conventional tool and find COG as shown in Figure 3 and same platform we can use for finding actual COG. From the result it is found that equipment is capable to measure a centre of gravity with approximately 95-98% accuracy. Same kind of results accuracy we are obtain using various parts and components.

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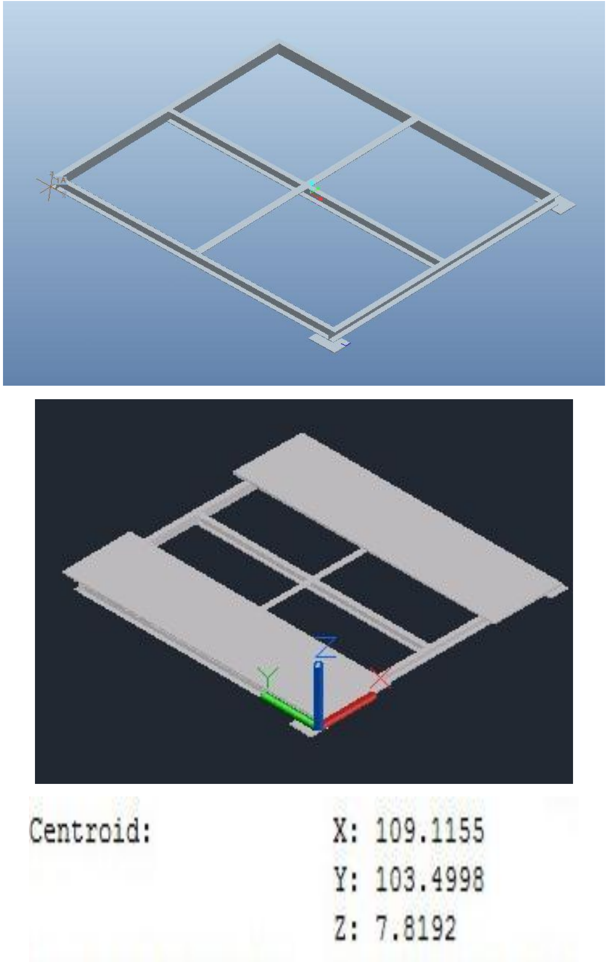

Fig. 3. Numerical value of COG using conventional tool

Fig. 4. Experimental setup of COG measuring using 4 load transducer method

Instrument measured value:

X: 109.995 cm; Y: 105.010 cm; Z: 6.06 cm

Error:

X: 0.80%; Y: 1.40%; Z: 2.42% (-ve)

III. RESULT AND DISCUSSION

With the help of this instrument we have measured the centre of gravity of our SUPRA SAE CAR by performing the experiment in two stages.

Fig. 5. Measurement of C.O.G. SUPRA SAE CAR

In first stage we are only consider our handmade automobile and in second stage we measured COG of car with driver and study the effect on COG on car.

The calculation starts from the car in normal condition as shown in figure 5. The car is at horizontal condition with no slope with the force distribution acting on the vehicle. The force is solved using equation (1 & 2) which is moment law of equilibrium.

Reaction on load cell (LC) = F_1 = 84.2 kg; Reaction on load cell (RC) = F_2 = 93 kg; Reaction on load cell (RS) = F_3 = 116.6 kg; Reaction on load cell (LS) = F_4 = 127.8 kg, Total weight of car: 421.6 kg; Length of frame (wheel base): 225 cm; Width of frame (wheel track): 211 cm.

Coordinate of COG in X axis from pivot point =

$$x = \frac{(F_2 + F_3)L}{(F_1 + F_2 + F_3 + F_4)}$$

= 130.43 cm

Coordinate of COG in Y axis from pivot point =

$$y = \frac{(F_3 + F_4)T}{(F_1 + F_2 + F_3 + F_4)}$$

= 104.89 cm

X dist. between pivot point and front axle: 26.3 cm
Y dist. between pivot point and front axle: 13.5 cm
Coordinate of COG in X direction = 130.43-26.3 = 104.13 cm
Coordinate of COG in Y direction = 104.9-13.5 = 91.39 cm

The calculation of the COG position continues by using the car weight on inclined position which have slope when weighing the car. Figure 6 shows the car on inclined position

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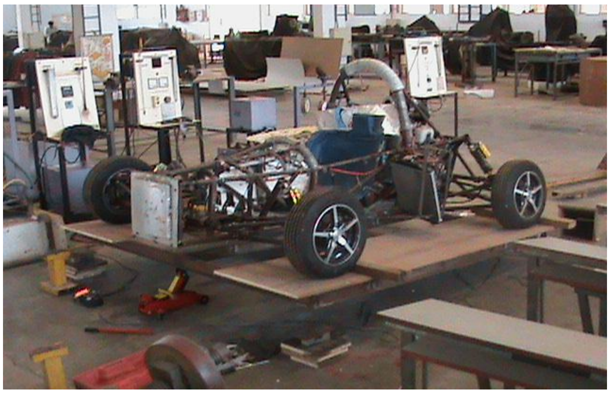

Fig. 6. Measuring The Height Of C.O.G. Of SUPRA SAE CAR

Reaction on load cell (LC) = F_1 = 84.2 kg; Reaction on load cell (RC) = F_2 = 93 kg; Reaction on load cell (RS) = F_3 = 116.6 kg; Reaction on load cell (LS) = F_4 = 127.8 kg ,Total weight of car: 421.6 kg; Reaction on load cell with Front elevated (RS) = F_3'= 123 kg, Reaction on load cell with Front elevated (LS) = F_4' = 125.05 kg ; Total weight of reaction during front elevated (W_f) = 248.05 kg; Length of frame (wheel base): 225 cm; Width of frame (wheel track): 211 cm ; Horizontal distance from pivot point to COG (b) = 130.43 cm; Radius of loaded wheel (R_L): 25 cm; Angle (Θ) = 3.5 (degree)
Height of centre of gravity from ground (h) =

$$h = R_L + \left(\frac{W_F l - Wb}{W \tan\theta} \right)$$

= 56.87 cm
Height of platform from the ground = 25 cm
Actual height of COG = 31.87 cm

A. Calculation of C.O.G with driver

Figure 7: Measuring of C.O.G. of Our SUPRA SAE CAR with Driver

Reaction on load cell (LC) = F1 = 99.15 kg;
Reaction on load cell (RC) = F2 = 108.7 kg;
Reaction on load cell (RS) = F3 = 134.25 kg;
Reaction on load cell (LS) = F4 = 148.65 kg;
Total weight of car: 490.75 kg; Length of frame (wheel base): 225 cm; Width of frame (wheel track): 211 cm.

Coordinate of COG in X axis from pivot point =

$$x = \frac{(F_2 + F_3)L}{(F_1 + F_2 + F_3 + F_4)}$$

= 129.7 cm

Coordinate of COG in Y axis from pivot point =

$$y = \frac{(F_3 + F_4)T}{(F_1 + F_2 + F_3 + F_4)}$$

= 104.45 cm
X dist. between pivot point and front axle: 26.3 cm
Y dist. between pivot point and front axle: 13.5 cm
Coordinate of COG in X direction = 129.7-26.3 = 103.4 cm
Coordinate of COG in Y direction = 104.45-13.5 = 90.95 cm

The calculation of the COG position continues by using the car weight on inclined position which have slope when weighing the car. Figure 5 shows the car on inclined position.

Figure 8: Measuring the Height of C.O.G. Of SUPRA SAE CAR (With Driver)

Reaction on load cell (LC) = F_1 = 99.15 kg; Reaction on load cell (RC) = F_2 = 108.7 kg; Reaction on load cell (RS) = F_3 = 134.25 kg; Reaction on load cell (LS) = F_4 = 148.65 kg; Total weight of car: 490.75 kg; Reaction on load cell with Front elevated (RS) = F_3'= 139.7 kg; Reaction on load cell with Front elevated (LS) = F_4' = 147.6 kg; Total weight of reaction during front elevated (Wf) = 287.3 kg; Length of frame (wheel base): 225 cm; Width of frame (wheel track): 211 cm; Horizontal distance from pivot point to COG (b) = 129.7 cm; Radius of loaded wheel (RL): 25 cm; Angle (Θ) = 3.5 (degree).
Height of centre of gravity from ground (h) =

$$h = R_L + \left(\frac{W_F l - Wb}{W \tan\theta} \right)$$

= 57.99 cm
Height of platform from the ground = 25 cm
Actual height of COG = 32.99 cm

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IV. CONCLUSION

Instrument can able to measure both C.O.G and weight. This is the fastest C.O.G measurement method. Total time to make a measurement of weight and 2 axis C.O.G is less than 2 minutes. The third axis requires another 5 minutes (most of which involves the tilting operation).All three axes of C.O.G can be measured in a single setup, eliminating the cost and risk. It is most suitable for very heavy parts with moderately precise C.O.G location acceptable tolerances. By using the latest force restoration transducers and optimum geometry, sensitivity can be adequate for most applications. This type of instrument is very easy to use. For a given C.O.G offset moment capacity and part weight, it is often the lowest cost automatic system.

V. ACKNOWLEDGMENT

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