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# Strain gauge based sensor for real-time truck freight monitoring

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## Abstract

This study aims to develop a weight monitoring sensor for trucks used in sugarcane harvesting. Finite element simulation of the behavior of the load of harvested sugarcane in the bin acting on the truck chassis was established. The position of the weight sensors was determined based on the stress distribution results. The weight sensors were then designed and constructed. A testing unit representing the truck chassis was constructed for calibration of the weight sensors. The results showed that sensors should be installed on the chassis at 180 mm above the rear wheel mounting position, where the maximum stress was 7.64 MPa. The designed weight sensor consisted of four strain gauges attached to the end of two 30 mm diameter bolts. All strain gauges were wired into a Wheatstone bridge circuit (full bridge). A linear relationship between the signals from the sensor and weight was found for weights greater than 1000 N. The weight of sugarcane can be monitored during harvest to do yield mapping and support the combine while it harvests the field.

**Keywords:** Chassis, Weight monitoring, Calibration, Truck

## 1. Introduction

The availability of agricultural labor is continually decreasing, and higher labor costs are adversely affecting the economics of sugarcane production [1-2]. The harvesting process needs the largest amount of labor and incurs the greatest costs. A sugarcane harvester can be used to replace labor and reduce the amount of burnt sugar cane. During a harvest, the harvester cuts sugarcane and conveys it to the truck, which travels beside the harvester until it reaches the end of each row. Hence, the field efficiency of harvesting process is low for small and short fields due to time lost while turning the truck and harvester at the end of each row [3-5]. The cost for harvesting is higher for smaller fields [6-8]. So, most of small farm owners have to burn sugarcane and do the harvest with manual labor because they are refused by the harvester operator.

For high performance, a field length of about 400 m is required [9]. Thus, farmers are encouraged to combine their small individual fields to form larger harvesting areas. A device that records the weight harvested from each small field separately during harvesting in the combined field is needed.

At present, there have been studies about weight monitoring systems using different approaches such as image processing for yield estimation and weight monitoring systems using ultrasonic instrument for crop production estimation. Marinello proposed image processing system to create a 3D height profile of the soil and crop surface. Unfortunately, large measurement errors were found at higher speeds [10]. Alternatively, the system using ultrasonic instruments has limited precision in bright light [11]. Moreover, these systems are of limited use in Thailand since most of harvesting is done under the dusty conditions of the dry season. In developed countries that produce sugarcane such as Australia and Brazil, in-field weight monitoring is done using a commercial load cell system mounted on a trailer pulled by a tractor. Due to the long distances between the fields and sugar refineries, ten wheel trucks are widely used instead trailers. Therefore, weight monitoring sensors that can be installed on ten wheel trucks were designed and calibrated to accurately determine the weight of sugarcane during the harvesting process.

## 2. Materials and methods

### *2.1 Materials*

The equipment used was a MITSUBISHI FUSO FN527S truck with a width (W) 2.50 m, length (L) 12.00 m, and height (H) 3.80 m (Figure 1). The open area of the truck bin was width 2.5 m, length 7.22 m, and height 2.3 m. The density of the harvested sugarcane, variety U-THONG3, is on average 453.4 kg/m$^3$ [12].

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**Figure 1** Truck dimensions

**Table 1** Material properties of the truck chassis

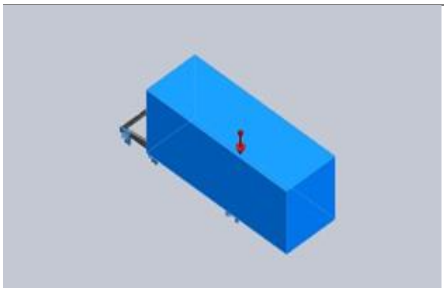
| Model Reference | Properties | |
|---|---|---|
|  | Name: | ASTM A36 Steel |
| | Model type: | Linear Elastic Isotropic |
| | Yield strength: | 2.5e+008 N/m$^2$ |
| | Tensile strength: | 4e+008 N/m$^2$ |
| | Elastic modulus: | 2e+011 N/m$^2$ |
| | Poisson's ratio: | 0.26 |
| | Mass density: | 7850 kg/m$^3$ |
| | Shear modulus: | 7.93e+010 N/m$^2$ |
| | Bulk density of sugarcane in box: | 490 kg/m$^3$ |

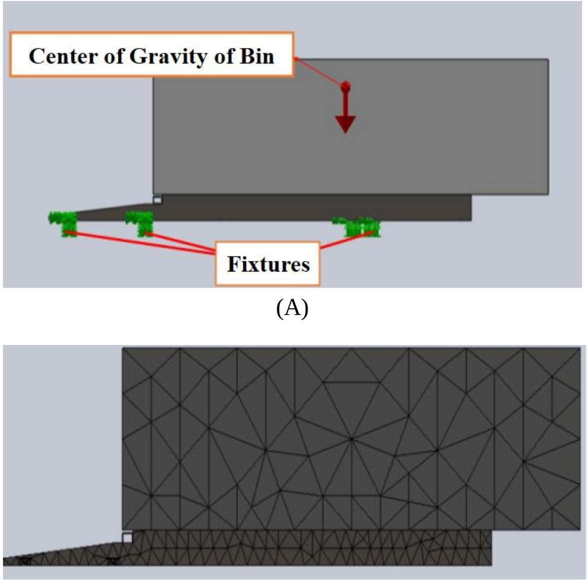
**Figure 2** model of chassis and binbox

*2.2. Methods*

*2.2.1 Stress distribution analysis*

The objective of using FEM in this study was to reduce the number of trial and error attempts to find an appropriate location to install weight monitoring sensors. Modeling was performed to simulate the size of the chassis and bin using SolidWorks (Figure 2). The directly modelled chassis was made of ASTM A36 steel with a density of 7850 kg/m$^3$. The bin was made of a plastic material with density 490 kg/m$^3$. It was a linear elastic in an isotropic medium with elastic modulus 2 x 1011 N/m$^2$, and a Poisson's ratio of 0.26 (Table 1) [13].

Since the material of truck chassis was ductile and we aimed to find the location that has highest range of stress, the von Mises stresses were compared. Analysis of the chassis using the SolidWorks simulation was performed as follows: 1) prepare the model of the chassis [14-16], 2) create the chassis model: a case study of static stress analysis, 3) determine the material for the model, 4) fix the set at the base of the chassis based on the fixed geometry of all six points (Figure 3A), 5) input the external load representing the gravity force of the sugarcane in the bin, and 6) create a mesh for the finite element method. A curvature based mesh with four Jacobian 4 points was used (Figure 3B). Analysis was performed using ANSYS software. Input load was varied at three levels; (1) weight of sugarcane for the full bin, (2) weight of sugarcane filled 2/3 of the bin, and (3) weight of sugarcane filled 1/3 of the bin with 14865, 18519 and 24030 elements, respectively. The location of the strain gauge attachment on the chassis was selected after considering the change of stress distribution simulated during the above procedure [17-19].



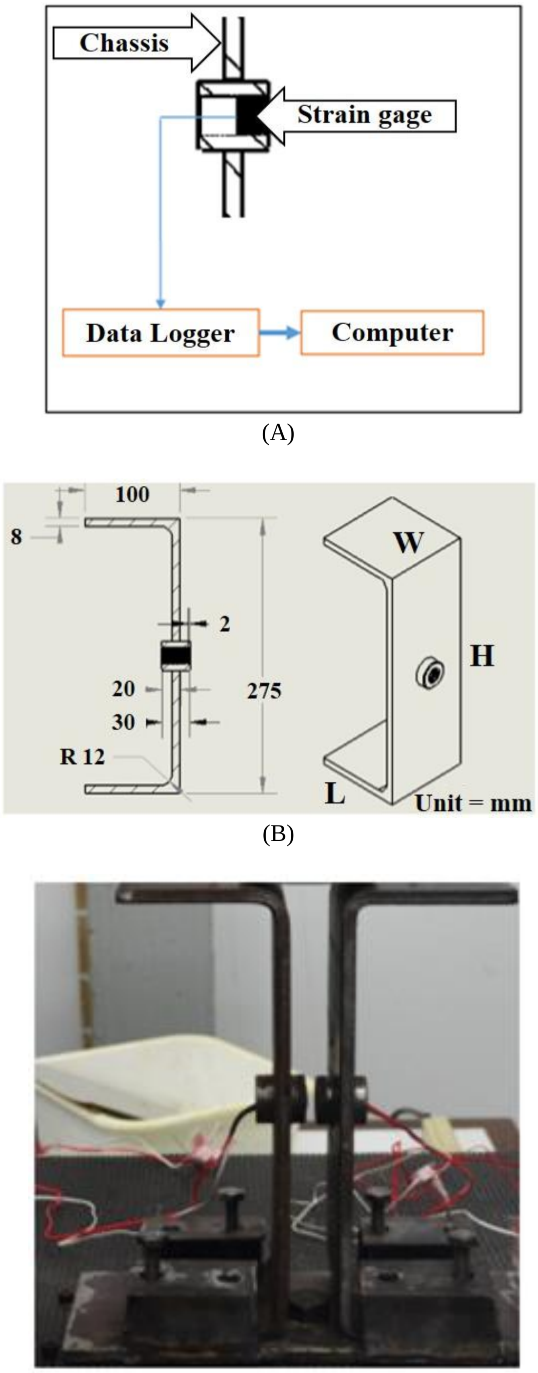
(A)

(B)

**Figure 3** Boundary condition (A) and element construction (B)

*2.2.2 Weight sensor design and calibration*

The installation location of the weight sensors on the chassis was determined based on the FEM results showing the areas where stress changed the most. Then, weight measuring equipment was designed to fit on a threaded mounting bolt with attached strain gauges. Figure 4A shows the signal acquisition system used to monitor weight in the truck. A weight sensor calibration was done to check the limits of the sensors and their linear response characteristics. Since the strain gauge were not attached directly to the chassis body, but rather it was attached by a bolt made of a different material that was assembled on the chassis body to provide some clearance. The unit dimensions were length (H) 275 mm, width (W) 100 mm, length (L) 100 mm, and thickness 8 mm. Holes with a diameter of 30 mm were drilled. This was the same size as the bolt holes on the truck



(A)

(B)

(C)

**Figure 4** Signal acquisition system (A), dimensions of testing unit (B), and the testing unit (C)

truck chassis. The set of weight measuring sensors was installed. The strain gauge is depicted in Figure 4B. The testing unit was assembled with weight measuring equipment and a strain gauge (Figure 4C).

Thin-film strain gauges were used (Figure 5B) with a diameter of 7 mm, coil length of 2 mm, resistance of 120 Ohms, a gauge factor 2.10 ± 1% of the TML(FCA-2-11-1L) type strain gauge, and a full bridge circuit. A bridge circuit typically consists of four gauges. The power supply was connected across the arms of the bridge at points a and c, and a signal detector was placed on the bridge arm at points b and d (Figure 5 A) [20-21].

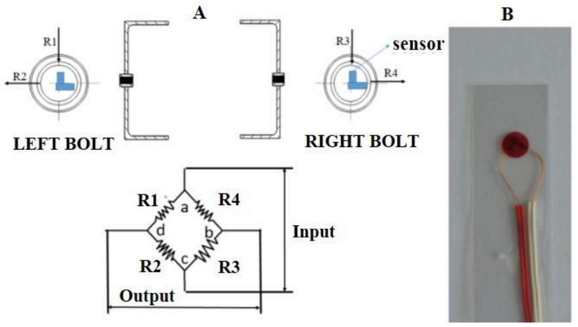


**Figure 5** Sensor’s Wheatstone bridge (full bridge) (A) and the thin-film strain gauges TML (FCA-2-11-1L) (B)

The weight measuring instruments were designed and a testing unit was created to simulate the truck chassis. Strength test calibration was performed using a universal testing machine (UTM). The sensor hardware was designed and fabricated. The size of the strain gauge was determined by considering the range of simulated strain results from the three levels of loading. The direction and position of each strain gauge on the sensor hardware was determined to best measure the compression loads acting on the truck chassis. All the strain gauges were then wired into a Wheatstone bridge (full bridge) to relate to the signals from the other directional loads. The weight sensors were attached to the testing unit which was then placed on a universal testing machine (UTM) (Figure 6). Compression loads of 1,000- 5,000 N were applied to the testing unit. The signals from the weight sensors were recorded at each 1,000N of compression load.

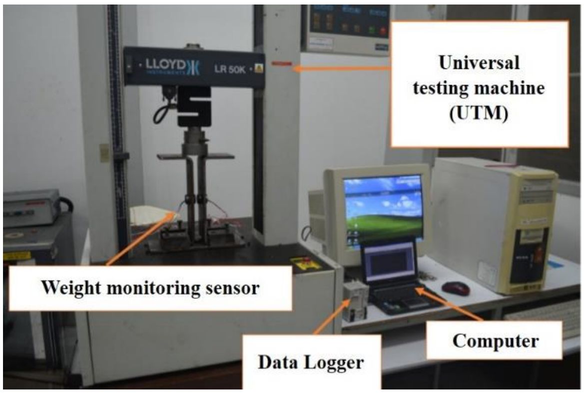


**Figure 6** Schematic of calibration equipment

## 3. Results

### *3.1. Result of stress distribution in chassis*

The stress distribution was expressed in the form of color contours. The maximum stress occurred at the corner of the chassis, close to the wheels. Its value was 24.275 MPa. A position 180 mm above the point of maximum stress was chosen for sensor attachment due to physical suitability. At this position, the stresses were equal to 1.51, 3.20, and 7.64 MPa (Figure 7) for each of the three levels of load.

Using SolidWorks, gravity simulation for each weight, 8.38, 14.94, and 21.51 tonnes, gave maximum stress values of 7.69, 20.43, and 24.27 MPa, respectively (Table 2). The relationship between the weights and the stress is shown in Figure 9.

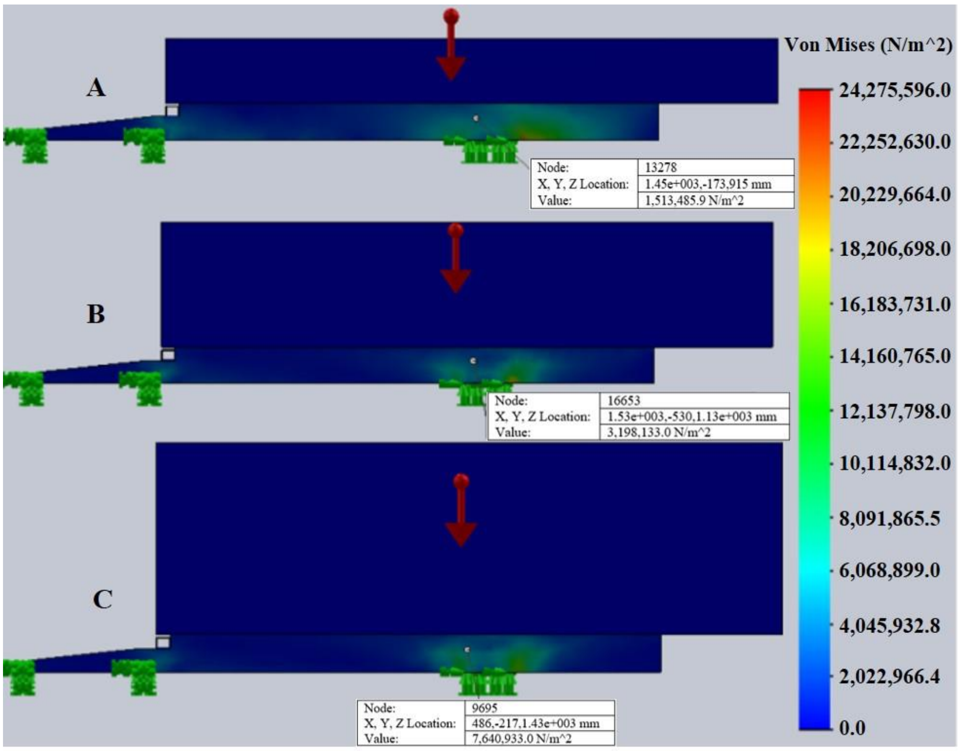


**Figure 7** Stress distribution with the weight of sugarcane filling one-third of the bin, (A) weight of sugarcane filling two-thirds of the bin (B), and weight of sugarcane for the full bin (C)

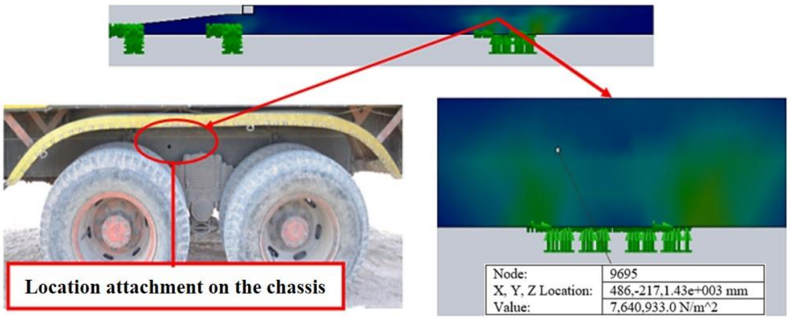


**Figure 8** Sensor attachment location on the chassis

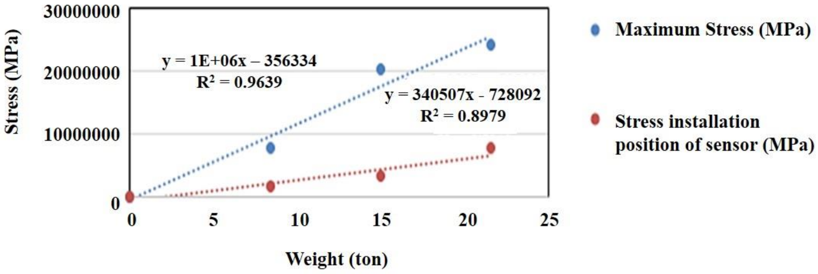


**Figure 9** The relationship between the weights and the stresses

**Table 2** Stress analysis results

| Weight (ton) | Maximum Stress (Pa) | stress at the installation position of sensor (Pa) |
|---|---|---|
| 0 | 0 | 0 |
| 8.38 | 7,696,820.00 | 1,513,485.90 |
| 14.94 | 20,430,428.00 | 3,198,133.00 |
| 21.51 | 24,275,596.00 | 7,640,933.00 |

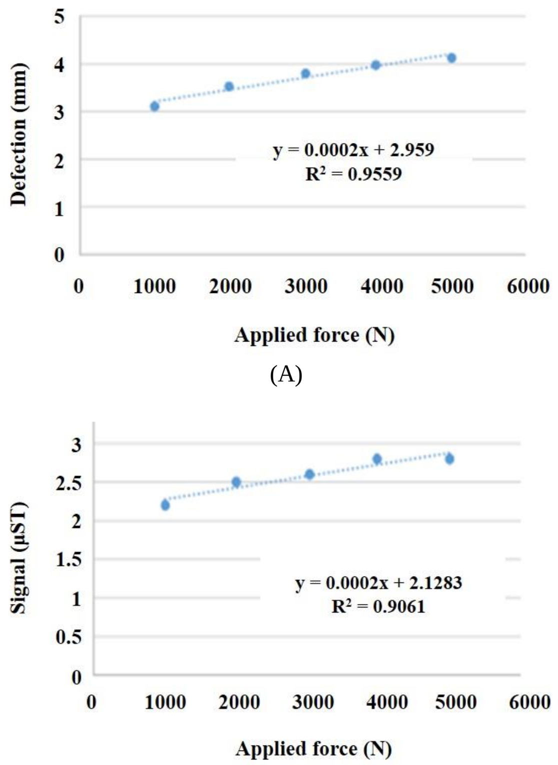
### *3.2 Weight sensor calibration results*

The calibration equation measured the values from the sets of strain gauges. The deflection of the test material indicated increased forces of 1005.71, 2006.78, 3038.70, and 3986.59 N, respectively (Table 3).

The values in Table 3 show the relationship between the force and the deflection. Force values with measured signals

**Table 3** Calibration results

| Maximum Force (N) | Deflection (mm) | signal of strain gage (μST) |
|---|---|---|
| 0.00 | 0.00 | 0.00 |
| 1005.71 | 3.11 | 2.20 |
| 2006.78 | 3.53 | 2.50 |
| 3038.70 | 3.80 | 2.60 |
| 3986.59 | 3.98 | 2.80 |



(A)

(B)

**Figure 10** The linear relationship between the applied force and deflection (A), and the linear relationship between the signal from the sensors and the applied force (B)

from the strain gauges are shown in Figure 10.

The calibration results had a linear relationship between the deflection (Y) and force (x) given by Y = 0.0002x + 2.959. The calibration results had a linear relationship between the signal from the weight (X) and the sensors (Y) of Y = 0.0002X +2.1283

## 4. Discussion

When the applied load was varied at three levels, i.e., a full of bin, two-thirds of a full bin, and one-third of a full bin, the maximum stress occurred at the corner of the chassis close to the rear wheels (Figure 7). It was less than the yield strength. The maximum stress increased linearly with increased loading (Figure 9). This stress distribution was similar to the results discussed by [14]. However, the area at the maximum stress position was too small. It was not possible to attach the sensors at this position and detect a change in weight. Thus, a position 180 mm above the maximum stress location was chose. It had a similar trend of stress response to applied loads as the position of maximum stress (Figure 9). Additionally, there was enough space to install the weight sensor (Figure 8).

Sensor deflection (mm) and signal (μST) increased linearly with the applied vertical load in the range 1000 to 5000 N (Figure 10). The calibration curve did not pass through the origin, thus, an offset value was used in the calibration equation. This offset might have been caused by the clearance between the sensor and the chassis. This is characteristic of bolt gauges [17]. Hence, the limitation of the developed sensors is that it should not be used for weight monitoring of loads less than 1000 N.

## 5. Conclusions

This study designed and analyzed sensors to measure the weight of harvested sugarcane. The results showed that the weight sensors should be installed on the truck chassis at 180 mm above the rear wheel. This is due the similar response behavior to the position of maximum stress and space limitations. The weight sensors consisted of four strain gauges attached to the ends of 30 mm diameter bolts. All the strain gauges were wired into a full Wheatstone bridge (full bridge) configureation. The calibration model for the weight sensor measurements was Y = 0.0002X +2.1283. This accurately predicts the weight carried by the truck ($R^2$=0.9061). This weight sensor should be used to measure weigh that produce forces greater than 1000 N due to a limitation of assembly clearance. Sugarcane weight can be monitored during harvesting which is important information to do yield mapping. Moreover it can be used to support the practice of combining the small fields of various farmers to increase harvesting field efficiency and reduce harvesting costs.

## 6. Acknowledgements

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