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Mass Flow Rate Measurement System Performance on Potato Harvesters

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ABSTRACT

A project was established to develop a procedure for the selection, design, installation, test and evaluation of mass-flow rate measurement systems for root crop harvesting and to assess the consistency and precision of the weighing systems incorporated into crop feed arrangements in both laboratory and field studies. Studies were conducted to evaluate conveyor belt weighing systems using an experimental apparatus and a commercial potato harvester. Two weighing systems were evaluated: (a) cantilever transducers fitted to the conveyor belt mechanism and (b) a load cell system supporting the total weight of the conveyor and crop. The results of laboratory studies with sugar beet/potatoes showed that the standard cantilever transducers gave the smallest percentage of standard deviation from the mean experimental error ranging from 1.43 kg (connected to one idler roller) to 2.61 kg (connected to three idler rollers) with an appropriate value equal to 0.54 kg (connected to two idler rollers). The load cell supporting system also gave the smallest percentage of standard deviation from the mean experimental error ranging from 1.56 kg (continuous side feeding) to 2.25 kg (side feeding from right side) with an appropriate value equal to 0.84 kg (steady state side feeding). Experiments were conducted in the laboratory and field to assess the effects of belt inclination and extraneous vibration, transferred from the tractor to the harvester, on the measurements of crop mass. The results of field studies with potatoes using the cantilever transducers showed that the most precise system performance was obtained when using the 125 mm idler wheels with standard deviation of the mean experimental error of the sample yield equal to 0.99 kg. The results of barn studies with potatoes using the load cell supporting system showed that there was a good linear relationship between the measured and weighed mass of the potato samples with standard deviation of the mean experimental error equal to 0.34 kg.

Keywords: Continuous measurement system, Harvesting, Mass flow, Potatoes, Root crops, Sugar beet.

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INTRODUCTION

Precision farming technology is a tool that can be utilized to manage yield variability within a field. This technology has the potential to optimize yields in each portion of the field to maximize returns and reduce environmental impacts (Earl *et al*., 1996; Fisher *et al*., 1997).

In order to optimize and monitor yields in different crops, research reports show that both combinable (Perez-Munoz and Colvin, 1994; Borgelt and Sudduth, 1992) and non-combinable crops (Walter *et al*., 1996; Godwin *et al*., 1999) are harvested using precision farming technology.

In non-combinable crops, such as sugar beet, potato, carrot, onion, tomato and citrus a wide range of different methods of weighing and yield monitoring have been used (Campbell *et al*., 1994; Hall *et al*., 1997; Hofman *et al*., 1995).

Godwin and Wheeler (1997) evaluated yield mapping by measuring the mass accumulation rate. This provides a system for

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recording the yield of high-value root crops using a trailer-based weighing system, which works on the basis of estimating the flow of material into a trailer or other holding tank by recording the incremental increases in the mass of the harvested crop.

Demmel *et al*. (1999) evaluated the performance of local yield detection on a trailed one-row offset lifting bunker-hopper potato harvester on the experimental farm scheme. The system worked well and the accuracy achieved, with a standard deviation of the relative errors of 4.1%, was similar to that of yield measurement systems used in combines.

The yield measurement equipment, consisting of a weighing frame, load cells, speed sensors and data-acquisition apparatus, was developed and tested both under laboratory and field conditions. The field observations confirmed the high accuracy attainable with the system applied in which the weighing accuracy ranged from 2.1% (too low) to 4.3%, (too high) with an average weighing accuracy of 1.06% (Van Canneyt and Verschoore, 2000).

Yield monitors for bulk crops such as sugar beet and potatoes, are still in the early stages of development, and are ideal candidates for the benefits of precision farming (Walter *et al*., 1996; Auernhammer and Demmel, 1999; Panneton and St-Laurent, 1999).

Mass flow measurements are carried out using a curved plate. A mass flow sensor, based on measuring the impulse flow colliding with the plate, was developed for sugar beet. A theoretical model of the beet flow over the turbines of the cleaning unit was calculated. From this model, the velocity of the beets was determined and the different parameters influencing the momentum were investigated. The momentum was indirectly calculated from the force extracted on the rack of the cleaning unit. A measurement device was constructed, minimizing the influence of harvesting conditions and material properties. After calibration, measurements were carried out on the cleaning unit of a Dewulf (two-phase system) and Agrifac (one phase system) (Hennens *et al*., 2003).

A site-specific sugar beet yield monitoring system was then developed and tested. Two weight-sensing systems (152 mm idler wheels attached to load cells and the replacement of two existing idlers on each side of the harvester outlet conveyor with slide bars) were developed, tested and evaluated on a laboratory test conveyor. Laboratory tests to predict accumulated weight showed a 2.5% error for the slide bar system and a 3.5% error for the idler wheel system (Walter and Backer, 2003).

A field study was conducted to evaluate three real-time weighing systems to measure sugar beet yield. There was no statistical difference between two of the sensors, but there was for the other one and the system provided unacceptable results. One of the systems provided reasonable accuracy and allowed for use of the on-board storage hopper (Hall *et al*., 2003).

In this study, both (i) cantilever transducers and (ii) load cell supporting systems were used in order to determine the basic principles of mass flow rate measurement for harvesting non-combinable crops such as sugar beet and potato. The objectives were to measure continuous mass flow, total mass and product yield and to find a more consistent and high precision weight-sensing system.

MATERIALS AND METHODS

This study was divided into three main sections:

1) Laboratory studies to evaluate the performance of both the cantilever transducers and load cell supporting systems on the prototype conveyor.

2) Evaluation of the effects of vibration and inclination of the harvester on the weighing systems.

3) Field studies involving performance evaluation of the cantilever transducers and load cell supporting systems in the field and a barn, respectively.

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Cantilever Transducer

Experimental investigations using the cantilever transducers were conducted to measure the continuous mass flow for root crop harvester. Each cantilever transducer was designed and instrumented with both the standard and differential Wheatstone bridge circuits to record output signal of flowing products over the conveyor either as a concentrated load at the end of the beam or on the beam longitudinally, respectively.

The output of the strain gauge bridges depends on gauge location since this affects the bending moment at the gauge. The sensitivity is significantly reduced using the differential gauge arrangement (Figures 3 and 4), but the bridge output is independent of the force location. In this case, it is dependent upon the distance (b-a) (Figure 1) on the beam, which should be as long as practicable.

The positioning of the strain gauges on the beams (1, 2, 3 and 4) and back of it (11, 12, 13 and 14) is shown in Figure 1.

The following connections were used to attach the cantilevers to the frame:

Connection between the Idler Roller and the Beam

The applied load (the loaded force location, B) as shown in Figure 2 at point A was calculated as follows and was found to be 5.18 kN:

$Load\ A = P \times L/m$

Where m is the distance from the load at A to the fixing hole.

Using the appropriate table, M6 was determined as the suitable screw for fixing the connector on the beam.

The angle of Connection between the Frame of the Conveyor and the Beam

To make a hole in the beam and fix the angle on the frame, calculations were made using following equation and the load on each hole was found to be 4.403 kN:

$P \times L = 2 \times n \times Shear\ force$

Again, the M6 screw was found to be suitable.

The transducer was connected to a digital voltmeter (DVM) and a power supply unit. The outputs of the two bridges were shown on the DVM at the same time. By applying loads from a minimum of 1 kg to a maximum of 10 kg on the beam and repeating the same process 3 to 5 times, the average calibration factors for the bridges were obtained as: 2.732 m VN^{-1} V^{-1} and 0.357 m VN^{-1} V^{-1}, respectively (Figures 3 and 4).

In order to compensate for the offsets of the load cells, they were measured directly from the electric board using a digital voltmeter.

The instrumented cantilever beams were connected to the idler rollers such that concentrated loads were applied at the free ends of the idler rollers, as shown in Figure 5. Based on connecting idler rollers to the beam, the width of the connected idler roller(s) was

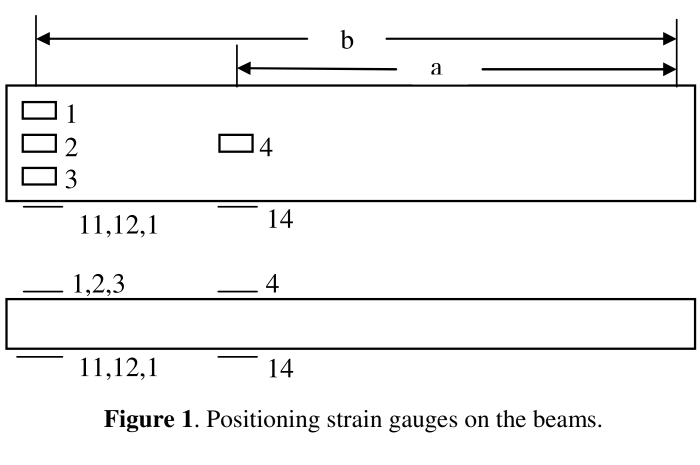

Figure 1. Positioning strain gauges on the beams.

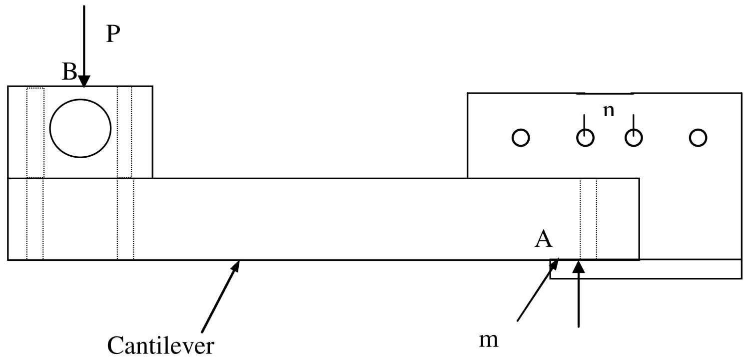

Figure 2. Schematic diagram of the cantilever beam connections.

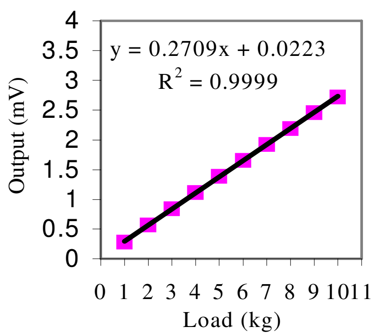

Figure 3. Sensitivity of the standard Wheatstone bridge.

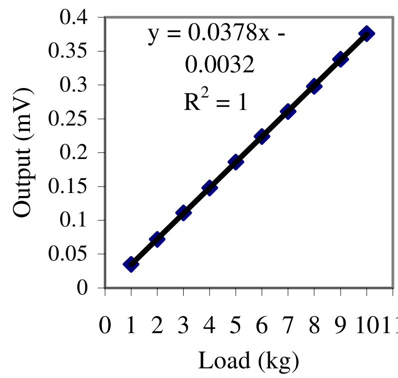

Figure 4. Sensitivity of the differential Wheatstone bridge.

considered as the sensitive zone. It is possible to achieve a reliable concentrated load using the appropriate length of sensing area.

The cantilever transducers were connected to the apparatus with the following arrangements:

Connecting the Transducer to one Idler Roller

The sensitive zone was 50 mm wide (as shown in Figure 5), so the time for recording the output signal was 0.08 s.

Connecting the Transducer to Two Idler Rollers

In order to increase the sensing area of the belt, two idler rollers were connected together. This made the sensing area of the belt sufficiently long to give enough time to weigh the mass adequately so that the system could capture the output signal and increase the accuracy of the measurement. The sensitive zone was 100 mm wide as shown in Figure 6.

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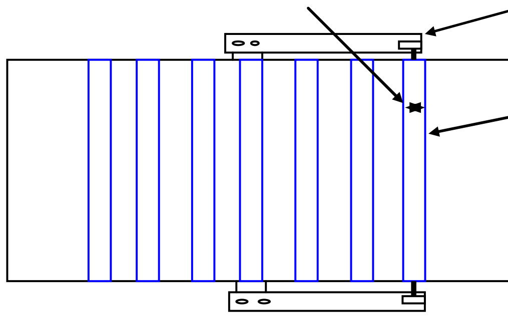

Figure 5. Schematic diagram of the instrumented cantilever beams connected to the idler rollers.

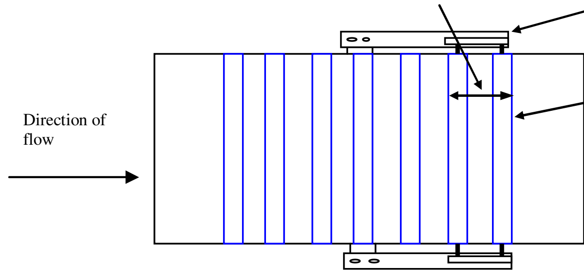

Figure 6. Schematic diagram of two idler rollers connected.

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Connecting the Transducer to Three Idler Rollers

Three idler rollers were connected together in order to evaluate system performance and accuracy. In this case, the sensitive zone was 200 mm wide as shown in Figure 7.

The experiments were performed using the feeder system to deliver the products on the conveyor with two different feeding methods: (a) continuous and (b) intermittent. Dif-

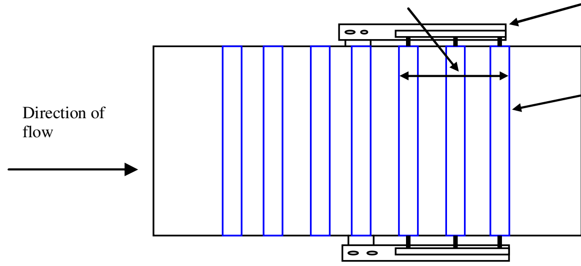

Figure 7. Schematic diagram of three idler rollers connected.

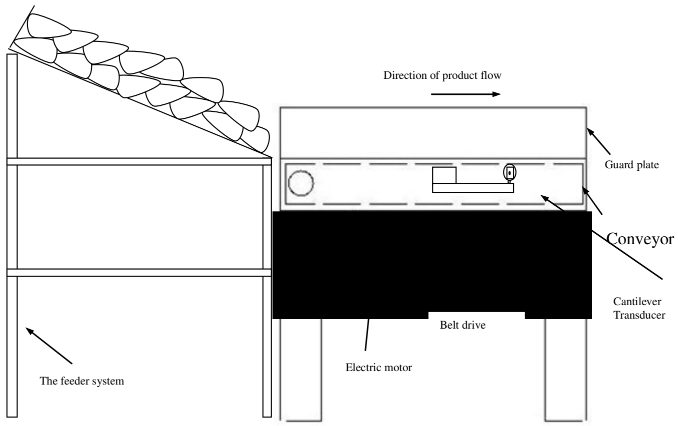

Figure 8. Schematic diagram of the feeder system.

ferent feeding methods were used in order to simulate the harvesting of produce in a field as shown in Figure 8.

In order to simulate combine harvesting of bulk crops in the field, the effect of both continuous and intermittent flows of sugar beet/potatoes as supplied to the end of the conveyor belt was studied.

Statistical analysis was employed to evaluate and determine the weighing system performance and compute the reproducibility, as shown for a typical example in the following calculations.

The effective belt length of the conveyor was determined using Equation (1):

$$L_e = \frac{\sum M}{W_A} \times S \times t \quad (1$$

The measured mass can be calculated using a mean value of the effective belt length based on 10 replications as shown in Equation (2).

$$W_m = \frac{\sum M}{(L_e)_m} \times S \times t \quad (2$$

Product flow rates can be calculated using a mean value of $(L_e)_m$ based on 10 replications using Equation (3):

$$F = W_M/t = (\sum M/(L_e)_m) \times S \quad (3$$

In order to evaluate precision and accuracy of weight sensing configurations, the experimental error was calculated for each treatment as shown in Equation (4):

$$Experimental\ error = \frac{|\ Experimental\ value - Eeighed\ value\ |}{Weighed\ value} \times 100 \quad (4$$

Total Mass Weighing System

Modification of the experimental apparatus using four load cells supporting the whole system was carried out to measure the performance of the belt weighing system with different types of feeding and feeder arrangements as shown in Figure 9.

Four tension/compression load cells with 100 kg rated capacities produced by PCM (Procter and Chester Measurements) were used in this study (A, D, B and C).

The load cells have different offsets, which were measured directly using a digital voltmeter from the electronic connector board.

It is assumed that the conveyor is supported on four elastic supports at the four load cells. The sum of the reactions gives the total mass on the belt at any given time, if the static forces due to the assembly weight are subtracted from the total load cell signals.

The most important design consideration in this system is the load applied at any point of the conveyor, which affects the four supporting points. In other words, the sum of

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the loads sensed by the four load cells will give the total mass of produce.

The produce (e.g. sugar beet or potatoes) was placed on the feeding system when the conveyor belt was running. The entire product that passed over the belt and four columns of the data sensed by the four load cells was recorded, using a data logger installed on a laptop computer. The total mass and flow rates for produce were calculated using a spreadsheet.

The load cells were located between the outside rough surfaces of the frame chassis and bolted. The whole frame was rigid and the frame of the conveyor was attached to it. The four load cells supporting the whole system were installed between the two frames as shown in the Figure 9.

Load cells were calibrated for both static and dynamic running conditions of the conveyor belt by placing a static mass on each and finding the effect of that mass on the others. In dynamic running of the conveyor belt, the sum of the output signals from the four load cells was equal to the output signal obtained from putting mass in the middle of the conveyor belt.

The average instrument calibration factor for the load cells is calculated as shown in Equation (5):

$$IC = \frac{The\,average\,sum\,of\,output\,signals\,from\,the\,four\,load\,cells}{Static\,mass}$$

$$C = \frac{15.234 mV}{74 kg} = 0.206\, mV/kg = 2.02 mV/N \quad (5$$

where:

The average output signal= 15.233 mV

Static mass= 74 kg.

Table 1 shows the experimental error of the different feeding configurations.

Field Perturbation

Field perturbation studies were carried out in two ways as follows:

a) Measuring vibration characteristics of the potato harvester working in the field using suitable transducer and recording

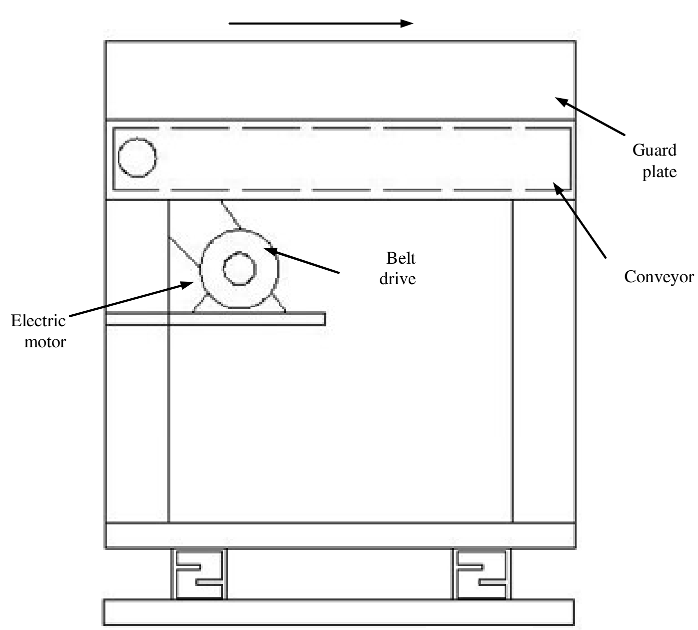

Figure 9. Schematic diagram of the load cell supporting system.

Table 1. Data obtained from calculating experimental error using the load cell supporting system.

Treatment number	Feeding form	Mean experimental error (%) [a]	Standard deviation (kg)
1) End-feeding from left side	Continuous and intermittent	3.07c	1.84
2) Side-feeding from left side	Continuous and intermittent	1.74ab	1.83
3) Side-feeding from full length	Continuous and	2.07abc	1.57
	steady state	1.28a	0.84
	Right and left hand bias	2.78bc	1.69
4) Side-feeding from centre	Continuous and intermittent	2.69bc	1.56
5) Side-feeding from right side	Continuous and intermittent	3.28c	2.25

[a] Difference level of Dancan's test in 5% provability

equipment.

Field measurement of vibration in terms of acceleration was done using a piezoelectric accelerometer with an acceleration magnitude of 3.16 m s^{-2}. The transducer was attached to a solid dielectric surface of the potato harvester. An electrical output is produced between surfaces of a solid dielectric when a mechanical input stress is applied to it. The position of the transducer was selected on the second chain web of the harvester where the crop entered the machine. The transducer was mounted independently of the second chain web so that it would measure acceleration transformed from the tractor to the harvester.

A moving/running average was used to remove the perturbation due to vibration from the transducer signals of crop mass and to eliminate noise for each second.

b) Simulating of change of the inclination angle of the weighing system on a laboratory rig.

The apparatus was set up with 5- and 10-degree inclinations in the following directions:

1. The left or right hand side,
2. Backwards and forwards.

The effective velocity of the crop on the conveyor belt was calculated using Equation (6):

$$V_e = \frac{W_A \times (L_e)_m}{\Sigma M \times t} \quad (6$$

Field Studies

Field studies were conducted to evaluate the performance of the cantilever transducers on the potato harvester. The position of the transducers was very important to avoid dirt tare and to obtain reliable output signals. Because of this, the transducers were positioned and installed at the end of the second web of the potato harvester.

The transducers and idler wheels were fixed on the harvester using appropriate attachments. Mechanical connections were used to attach the transducers to the chassis of the harvester and to adjust the transducers and idler wheels connected to the web. Idler wheels were connected between the transducers and the second web (Figure 10).

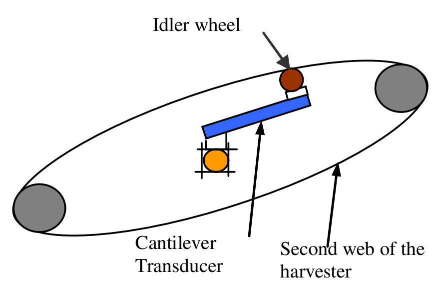

Figure 10. Schematic diagram of the transducer connected to the second web of harvester.

In order to perform the calibration procedure, a static calibration was made to establish linearity between the absolute and measured load. The experiment was carried out with known weights on the sensitive area of the second web of the potato harvester. Different weights from 0.5 to 5.0 kg were applied to determine the sensitivity of the weighing system. The output signal was recorded using the data logger. The data obtained was analyzed and the calculations were performed using a spreadsheet. Figure 11 shows a linear correlation between the absolute and measured weight with no hysteresis.

Field Experiments

Field experiments were conducted using cantilever beams fixed on the second web of the potato harvester. The signals were sent via the electric board to a laptop computer.

The samples collected for the experiments were:

(i) Empty harvester at the start of harvesting.

(ii) Harvester full of potatoes at the start and end of the recording time.

(iii) Empty harvester after delivering potatoes into the trailer.

Potato yield was calculated using Equations (6) and (7):

$Y= (10\times F)/(w\times V)$ (7

where:

$F= W \times S$ (8

The calculated potato yield was determined using the weight of the harvested products for the harvested area.

The weighing system was evaluated and tested with high and low yield (5.02 and 3.52 kg m^{-2}, respectively) of the produce for both wet and appropriate harvesting soil conditions (14-18% and 22-28% w.b., respectively). Idler wheels with 50 (standard idler wheel diameter on the harvester) and 125 mm diameter (results obtained from the laboratory studies) were used in the weighing system to evaluate their performance.

Barn Experiments

Barn studies were organized to evaluate performance of the load cell supporting system using the harvester. Two transducers were constructed and installed on the harvester in place of two idlers as shown in Figure 12. The position of the transducers was very important in obtaining a reliable output signal for products passing over the weighing system.

Static calibrations were performed on the

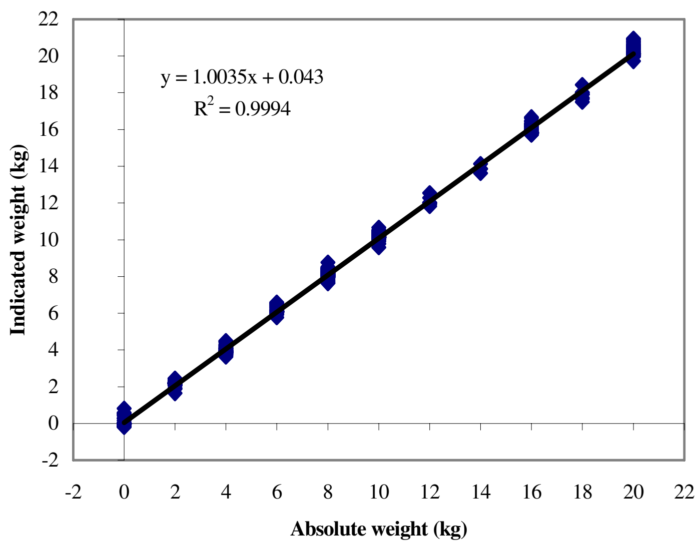

Figure 11. Diagram showing the correlation between measured and absolute weight.

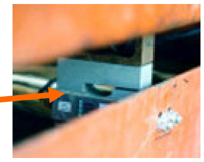

Figure12. Diagram of the load cell supporting system in the potato harvester.

cross conveyor of the potato harvester. Different weights from 1 to 5 kg were applied to determine the sensitivity of the weight sensing system.

A dynamic calibration procedure was conducted using known weights on the measuring zone that sensed the load which was determined by the weighing system. The calibration procedures were carried out using the different weights (1 to 5 kg) and conditions on the cross conveyor of the potato harvester.

The mean effective belt length was 0.205 m, which is equal to the mean actual length of one cell of the cross conveyor (0.193≤ L_A≤ 0226m).

Potatoes were delivered to the harvester using the feeder conveyor and passed over the weighing system then collected in a hanging bag.

RESULTS AND DISCUSSION

Laboratory studies showed that connecting to the two idler rollers, using the standard cantilever transducer, together with end-feeding from the left hand side of the conveyor belt was the best weight-sensing configuration to show weighed mass versus measured mass. Results are shown in Tables 2-4. The optimum result according to analysis of variance and Duncan's new multiple range tests (DMRT) to compare the treatment means is shown in Table 3.

The 95% confidence interval of the mean measured mass was between 30.62 and 31.37 kg with a standard deviation of 0.377 kg. In contrast, using the differential cantilever transducers showed that the 95% confidence interval of the mean measured mass was between 29.75 and 31.25 kg with a standard deviation of 0.75 kg.

Table 2. Data obtained from connecting to two idler rollers.

Run No.	Accumulated mass (kg)	L_e (m)	Measured mass W_M (kg)	Flow rate (kg/s)
1	434.35	0.182	31.32	19.51
2	425.25	0.178	30.66	19.10
3	430.14	0.180	31.01	19.32
4	424.44	0.184	30.6	19.06
5	436.08	0.183	31.44	19.58
6	424.04	0.178	30.57	19.05
7	428.33	0.179	30.88	19.24
8	425.17	0.178	30.65	19.09
9	424.67	0.178	30.62	19.07
10	433.16	0.181	31.23	19.45
Average		0.180	30.90	19.25

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Table 3. Data obtained from calculating experimental error using cantilever transducers.

Treatment	Number of idler roller	Mean experimental error (%) [a]	Standard deviation (kg)
Standard cantilever	One	1.56a	1.43
	Two	1.03a	0.54
	Three	2.42ab	2.61
Differential cantilever	One	3.35b	2.73
	Two	1.55a	2.57
	Three	2.3ab	3.29

[a] Difference level of Dancan's test in 5% provability

For the load cell supporting system, it was found that in the experiments where both continuous and intermittent crop feed were used, there were no significant differences between the appropriate effective belt lengths. The most accurate results according to statistical analysis are shown in Table 4.

As shown in Table 4, side feeding, using the full length of the conveyor belt for steady state crop feed, showed the best weight-sensing configuration with the most consistent performance of the weighing system arrangement. The 95% confidence interval of the mean measured mass was between 87.66 and 90.66 kg with a standard deviation of 1.38 kg. Therefore, the most consistent arrangement was treatment 1, where the produce had sufficient residence time to be weighed using the weight-sensing system.

The field perturbation experiments were performed to measure the effects arising from extraneous vibration and harvester inclination. The results of the dynamic measurement (during harvesting potatoes) showed that the average acceleration amplitude due to machine vibration was 2.91 m s^{-2} with a standard deviation of 0.324 m s^{-2}. The 95% confidence limit was ±0.17 m s^{-2}. The results also showed that the average measured acceleration magnitude, which was transferred from the tractor to the harvester, was less than that of the calibration level of acceleration magnitude (3.16 m s^{-2}) using the accelerometer. The sampling frequency was determined in an appropriate range in order to avoid aliasing and to eliminate vibration effects because of the high acceleration magnitude. The vibration did not influence the weight measurement systems when an appropriate moving average method was used in the data analysis. The combination diagram of both the acceleration magnitude and the signal frequency before and after processing were obtained using a spreadsheet as shown in Figures 13 and 14, respectively.

The inclination experiments were conducted at 5 and 10 degrees in different directions- left or right hand side and backward and forward-using the load cell supporting system with end feeding from the left hand

Table 4. Experimental results using the load cell supporting system.

Treatment number	Feeding form	Mean experimental error (%) [a]	Standard deviation (kg)
1) Side feeding from the full length	Steady state	1.28a	0.84
2) Side feeding from the left side	Continuous and Intermittent	1.74ab	1.84
3) Side feeding from the full length	Continuous	2.07abc	1.57

[a] Difference level of Dancan's test in 5% provability

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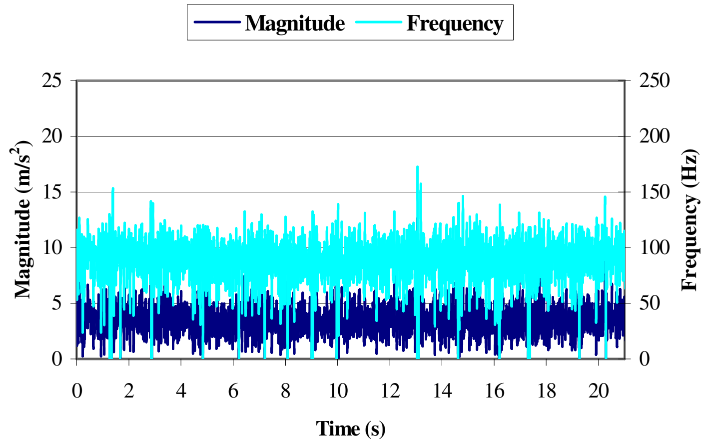

Figure 13. Diagram of unprocessed output signals obtained from the acceleration magnitude and signal frequency.

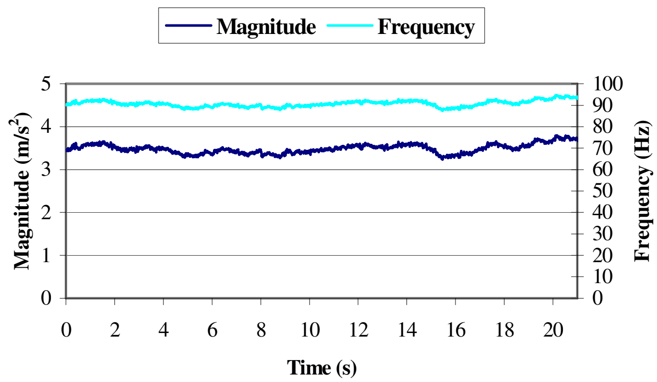

Figure14. Diagram of processed output signals obtained from the acceleration magnitude and signal frequency.

side of the conveyor belt. The results are shown in Table 5.

As shown in Table 5, effective velocity of the potatoes on the conveyor belt significantly differed for the 5- and 10-degree tilt angles.

For the backward inclination, the potatoes were rolling back down the conveyor because they were not stable on the smooth surface of the belt. The effective velocity was less than that of the conveyor speed (0.618 m s^{-1}) at the 10º tilt angle, resulting in a 6.3% error in flow rate; however, this differed from the normal speed by only 2.43% at the 5º slope, which was comparable to the limits of experimental error.

For the forward inclination at both tilt angles, the effective velocity of the potatoes was greater than the normal conveyor belt speed, resulting in errors of 8.9% and 15.4% for the 5º and 10º tilt angles, respectively.

In practice, crop rolling on the conveyor belt will be much reduced or eliminated when using a chain web or rod link conveyor on a root crop harvester. The crop transportation speed may then be independent of the inclination angle up to 10 degrees. The crop flow rate measuring belt may also be designed with slats, for example, to prevent crop acceleration under gravity if the harvester is tilted.

Furthermore, inclination can be measured using an inclinometer and an appropriate cor-

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Table 5. Mean effective velocity of the crop for backward and forward inclinations up to 10°.

Tilt	5° a		10° b	
Mean effective velocity	Backward	Forward	Backward	Forward
($m\ s^{-1}$)	0.633	0.673	0.579	0.713

Table 6. Results obtained using 125 mm idler wheels (IDW) connected to the transducers to harvesting high yield.

Treatment	Average measured sample yield ($kg\ m^{-2}$)	Flow rate ($kg\ s^{-1}$)	Population yield measured by farmer ($kg\ m^{-2}$)	Mean experimental error (%) [a]	Standard deviation (kg)
-125 mm IDW with short recording time	5.02	6.65	4.986	0.877a	0.99
-125 mm IDW with long recording time	5.02	6.65	4.983	1.271ab	0.97
-125 mm IDW with soil muddy condition	5.013	6.64	4.959	1.618ab	1.13
-50 mm IDW	3.046	4.04	3.004	2.092b	1.47

[a] Difference level of Dancan's test in 5% provability

rection factor applied to the effective belt velocity. This requires further work to establish the required relationship between slope angle and effective velocity.

Field studies using a potato harvester were conducted to test and evaluate the performance of both the standard cantilever transducers and load cell supporting systems. The standard cantilever transducers were installed on the potato harvester. The installation position was vital for reducing tare dirt and tare sources such as those caused by soil, clods and stones. The most consistent and precise result was achieved using 125 mm idler wheels connected to the transducers with the lowest mean experimental error of 0.877% of the measured sample yield and the farmer-measured population yield using the t test. Since all the potatoes had an adequate residence time to be stable and weighed without bouncing on the second web of the potato harvester when they passed over the weighing system, this weight-sensing configuration proved to be the optimum arrangement. The result obtained is shown in Table 6.

A data reduction method using a moving average was used to suppress signal noise. The moving average was applied based on the working width or distance between two rows (172.7 cm) (Campbell *et al.* 1994). A 53-point moving average according to the sampling frequency was used to obtain a value for each second of sampling time.

The 95% confidence interval of the mean measured sample yield was between 4.956 and 5.084 kg m^{-2} with a standard deviation of 0.064 kg m^{-2}.

A long recording interval, such as five or six minutes, reduced the effect of the uneven potato flow on the yield values (5.02 kg/s for high yield).

Dirt tare weight was measured under both dry and wet soil conditions. In dry conditions, measured dirt tare was 3.8 % (300 kg out of 7916.5 kg), whereas in muddy conditions the dirt tare was 12.25% (1100 kg out of 8977 kg). Muddy conditions caused the dirt tare value for the weighing system to be more variable than in dry conditions because soil adhered to the transducers and introduced errors into the recording of crop mass.

Barn studies were conducted to evaluate the load cell supporting system. These showed that there was a good linear relationship (Figure 11) between measured and weighed mass (R^2= 0.9994). The results obtained are shown in Figure 15.

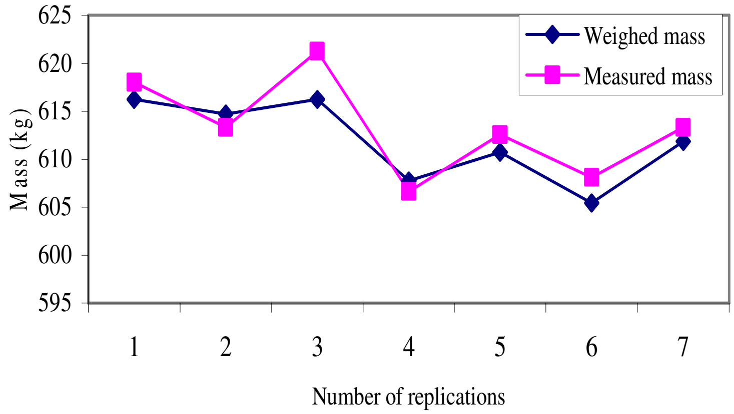

Figure 15. Data obtained from the measured versus weighed mass.

This was because of the choice of appropriate positions for the load cells underneath the cross conveyor of the potato harvester. The mean experimental error was 0.57% with a standard deviation of 0.336 kg. The 95% confidence interval of mean error was between 0.232% and 0.904%. The lower percentage of experimental error shows more consistency and precision of the performance of weight sensing configuration, for which all the potatoes had sufficient residence time to remain in the cells of the cross conveyor during the time they were weighed without bouncing when they passed over the weighing system.

CONCLUSIONS

1. Laboratory studies of both systems, properly designed and installed to provide mass flow rate measurement, resulted in: experimental error ranging from 1.03% to 3.35% with optimum results obtained when using cantilever beams with giving an error of 1.03% with standard deviation of 0.54 kg; the load cell supporting system resulted in experimental error ranging from 1.28% to 3.28% with the lowest error equal to 1.28% and standard deviation of 0.84 kg.
2. Inclination experiments using the load cell supporting system indicated that for a backward inclination, the effective velocity of potatoes on the conveyor belt was less than that of the conveyor speed (0.618 m s^{-1}) at a 10º tilt, but differed from that of the normal speed for the 5º slope. For the forward inclination, at both tilt angles, the effective velocity of potatoes was greater than that of the normal conveyor belt speed.
3. The average measured acceleration magnitude was 2.91 m s^{-2}, which was less than that of the calibration level of acceleration magnitude (3.16 m s^{-2}) using the accelerometer. A sampling frequency of 90.9 Hz was also determined as an appropriate range in order to avoid aliasing and to eliminate vibration effects due to the high acceleration magnitude.
4. Field experiments with the farmer potato harvester showed that fitting the standard cantilever transducers connected to 125 mm idler wheels was the most consistent configuration, where the larger diameter simulated the two-idler roller arrangement, with an average measured crop sample yield of 5.02 kg m^{-2}. This arrangement resulted in the lowest mean experimental error of the sample yield, equal to 0.877% a with standard deviation of 0.99 kg.
5. Barn experiments using a potato harvester showed consistent results using the load cell supporting system. Linear regression analysis between the measured and

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weighed mass of potatoes showed excellent correlation (R^2= 0.9994) with mean experimental error of 0.57% and standard deviation of 0.336 kg.

Nomenclature

L_e= Effective length of the beam applied in the measurements, m
L_A= Actual length of the cross conveyor cell, m
L= Length of the beam, m
m= The distance from the load at load point, m
ΣM = The accumulated mass of the material over the total period of a run summed for all sampling time intervals, kg
W_A= Actual or known mass of products found by direct weighing, kg
S= Conveyor belt speed, m s^{-1}
t= Time base that shows the start point of the test and the end point, s
W_M= Measured mass, kg
$(L_e)_m$= Mean effective belt length of the conveyor, m
F= Flow rate of material over belt, kg s^{-1}
V_e= Effective velocity of the crop on the conveyor belt, m s^{-1}
W= Measured mass of products per meter length of the second web of the potato harvester, kg m^{-1}
Y= Potato yield, ton ha^{-1}
w= Harvester working width, m
V= Ground speed, m s^{-1}.

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عملکرد دستگاه اندازه‌گیر جریان پیوسته جرمی در ماشینهای برداشت سیب زمینی

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چکیده

این تحقیق براساس توسعه روند انتخاب، طراحی، اتصال، آزمایش و ارزیابی سیستمهای اندازه گیری جریان پیوسته جرمی به منظور برداشت محصولات غده‌ای (سیب زمینی وچغندرقند) پایه‌گذاری شده و برای دستیابی به سیستم اندازه‌گیری جریان پیوسته جرمی دقیق و پایدار بر اساس طول مؤثر تسمه نقاله تغذیه در ارتباط با روشهای تغذیه محصول غده ای در آزمایشگاه و مزرعه، بررسی و ارزیابی های لازم انجام گرفته است. آزمونها بر اساس ارزیابی سیستمهای اندازه‌گیری جرمی غده‌ها در تسمه نقاله با استفاده از نمونه آزمایشگاهی و کمباین برداشت سیب زمینی انجام شده است. دو سیستم اندازه‌گیری جرمی مورد ارزیابی قرار گرفتند که عبارتند از: ۱- مبدل یکسر درگیر متصل به مکانیزم تسمه نقاله و ۲- حسگر بار نگهدارنده وزن کل نقاله تغذیه و محصول. نتایج آزمونهای آزمایشگاهی نشان داد که سیستم مبدل یکسر درگیر استاندارد وحسگر بار دارای کوچکترین انحراف معیار از متوسط خطای آزمایشی با مقادیری به ترتیب مساوی ۰/۵۴ و ۰/۸۴ کیلوگرم بودند. مبدل‌های یکسر درگیر استاندارد زمانی که به دو عدد غلتک هرزگرد در تسمه نقاله متصل شده بودند، کوچکترین انحراف معیار از متوسط خطای آزمایشی حاصل گردید. آزمایشات در آزمایشگاه و مزرعه جهت دستیابی به اثر شیب تسمه نقاله و ارتعاشات انتقالی از تراکتور به ماشین برداشت روی سیستمهای اندازه‌گیری جرم محصول برنامه‌ریزی و انجام گردید. مطالعات مزرعه‌ای برای آزمایش و ارزیابی سیستم مبدل یکسردرگیر متصل به چرخ هرزگرد ۱۲۵ mm روی ماشین برداشت سیب‌زمینی انجام گردید. نتیجه انجام آزمایشات نشان داد که دقیقترین عملکرد سیستم اندازه‌گیری زمانی بود که از چرخهای هرزگرد به قطر۱۲۵ mm استفاده گردید و انحراف معیار متوسط خطای آزمایشی عملکرد نمونه برابر با ۰/۹۹ کیلوگرم بوده است. مطالعه در محوطه مزرعه برای انجام آزمایش و ارزیابی سیستم حسگر بار با استفاده از ماشین برداشت سیب‌زمینی برنامه‌ریزی گردید. نتایج نشان داد که رابطه خطی خوبی بین جرم اندازه‌گیری شده و وزن شده نمونه‌های سیب‌زمینی وجود دارد (R^2=۰/۹۹۹۴). انحراف معیار متوسط خطای آزمایشی ۰/۳۴ کیلوگرم بوده است.