Investigations on Performance of a Continuous Mass Flow Rate Measurement System for Potato Harvesting

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ABSTRACT

This project was established to develop a process for the selection, design, installation, test and evaluation of mass-flow rate measurement systems for root crop harvesting. Also to assess consistency and precision of the weighing systems incorporated with crop feed arrangements, laboratory and field studies were carried out. Experiments were conducted to evaluate conveyor belt weighing systems using an experimental apparatus and 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 the mean experimental error ranged from 1.56% and standard deviation from 1.43 kg (connected to one idler roller) to 2.42% and 2.61 kg (connected to three idler roller) with an appropriate values equal to 1.03% and 0.54 kg (connected to two idler roller). The load cell supporting system also gave the smallest persentage of the mean experimental error ranged from 2.07% and standard deviation from 1.57 kg (continuous side feeding) to 1.74% and 1.84 kg (end feeding) with an appropriate value equal to 1.28% and 0.84 kg (steady state side feeding). Experiments were conducted in the field to assess the effects of extraneous vibration, transferred from the tractor to the harvester, on the measurements of crop mass. The results of field studies using the two rows potato harvester equipped with the cantilever transducers showed that the most accurate system performance was when using the 125 mm idler wheels with the mean experimental error of the sample yield equal to 1.07% with standard deviation of 0.98 kg. The results of barn studies using the harvester equipped by the load cell supporting system showed that there was a good linear relationship between the indicated and weighed mass of the potato samples with the mean experimental error equal to 0.57% and standard deviation of 0.34 kg.

Keywords: Mass flow, continuous measurement system, root crops, harvesting, potatoes, sugar beet

1. INTRODUCTION

Precision farming technology is a tool used by farmers to manage yield variability within a field. This technology has the potential to optimise yields in each portion of the field to maximise returns and reduce environmental impacts (Earl et al., 1996 & Fisher et al., 1997). In order to optimise and monitor yields in different crops, recent research shows that both combinable (Perez-Munoz et al., 1994; Borgelt et al., 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, potatoes, carrots, onions, tomato and citrus, a 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 mass accumulation rate. This provides a system to record 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 incremented increases in the mass of the harvested crop. The yield measurement equipment, consisting of a weighing frame, load cells, speed sensors and data-acquisition apparatus, was developed and tested both in laboratory and field conditions. The field observations confirmed the attainable high accuracy of the applied system, where the weighing accuracy ranged from -2.1% (too low) to 4.3% (too high) with an average accuracy of +/-1.06% (Van Canneyt T. and Verschoore R., 2000). A site-specific sugar beet yield monitoring system was developed and tested. Two weight-sensing systems were developed, tested and evaluated on a laboratory test conveyor. One system used 152 mm idler wheels attached to load cells. The second system replaced two existing idlers on each side of the harvester outlet conveyor with slide bars covered with UHMW plastic. Laboratory tests results showed typical weight errors ranged from 2% to 3% with an average error of 2.3% (Walter et al., 2003).

1.1 Objectives

In this study, both (i) cantilever transducers and (ii) load cell supporting systems were used in order to determine the fundamentals of mass flow rate measurement for harvesting non-combinable crops such as sugar beet and potatoes. The objectives were to measure continuous mass flow, total mass and yield of the products and to find a more consistent and high precision weight-sensing system (Mostofi Sarkari, 2000).

2. MATERIALS AND METHODS

This study was carried out in three main sections:

1) laboratory studies to evaluate the performance of both the cantilever transducers and load cell supporting systems on the apparatus;

2) evaluation of the effect of vibration and inclination of the harvester on the weighing systems; and

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

In this paper, field perturbation (vibration test) and evaluation of the transducers performance will be considered during potato harvesting using a commercial harvester.

2.1 Cantilever Transducer

Experimental investigations using the cantilever transducers were conducted to measure the continuous mass flow of the root crop harvester. Each cantilever transducer was designed and instrumented with both standard and differential Wheatstone bridge circuits to record output signal of products flowing over the conveyor either as a concentrated load at the end of the beam or on the beam lengthways, respectively. The output of the strain gauge bridges depends on the location of the gauge since this affects the bending moment at the gauge. The sensitivity is significantly reduced using the differential gauge arrangement but the bridge output is independent of the location of force impact. In this case, it is dependent upon the distance between fixed and free end on the beam , which should be as long as practicable.

The average calibration factors for bridges were obtained as: 2.732 $mVN^{-1}V^{-1}$ with R^2=0.9999 and 0.357 $mVN^{-1}V^{-1}$ with R^2=1.0, respectively.

2.2 Total Mass Weighing System

The load cells supporting the whole system were used to measure the performance of the belt weighing system with different type of feeding and feeder arrangements. Four FZ (S beam) tension/compression load cells (PCM) were used in this study.

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 the load sensed by the four load cells will give the total mass of the product. The load cells were calibrated in static and dynamic mode (conveyor belt running). The static calibration was executed by putting a static mass on each load cell and finding the effect of that mass on the others. In the dynamic mode (conveyor belt running), 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 in static mode.

2.3 Field Perturbation

Field perturbation study was to measure vibration characteristics of the two rows potato harvester (Benedict Model) working in the field using a suitable transducer and recording equipment.

Field measurements of vibration in terms of acceleration were made possible using a piezoelectric accelerometer. The accelerometer was attached to a solid dielectric surface of the 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 enters the machine. The transducer was mounted independently of the second chain web so that it would measure the transformed acceleration from the tractor to the harvester.

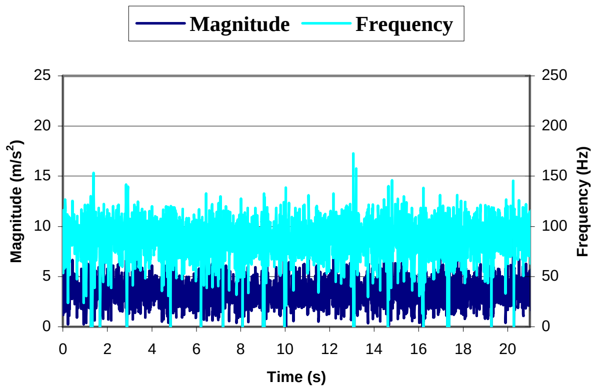
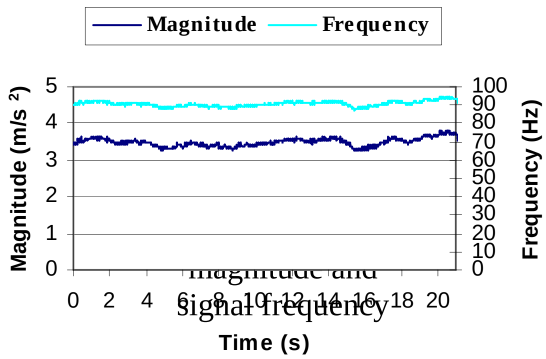


Fig.1. Diagram of unprocessed output signal obtained from



magnitude and signal frequency

Fig. 2. Diagram of processed output signal obtained from the acceleration magnitude and signal frequency

The combination diagram of both the acceleration magnitude and the signal frequency before and after processing were obtained as shown in Figs. 1 and 2, respectively. Data processing procedure was using a moving / running average to remove the perturbation due to vibration from the transducer signals of crop mass and eliminate noise for each second. A sampling frequency of 90.9 Hz was also determined in an appropriate range in order to avoid aliasing and eliminate vibration effects due to the high acceleration magnitude.

2.4 Field Studies

Field studies were conducted to evaluate performance of the cantilever transducers on the potato harvester. The position of the transducer 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 harvester. The constructed connections were used to attach the transducers to the chassis of the harvester and adjust the transducers and idler wheels connected to the web. The idler wheels were connected between the transducers and the second web(Fig. 3).

In order to perform the calibration procedure, a static calibration was made to establish linearity between the absolute and indicated load. The experiment was carried out with known weights on the sensitive area of the second web of the 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. A linear correlation between the absolute and indicated weight was obtained with the lowest hysteresis (Fig 4.).

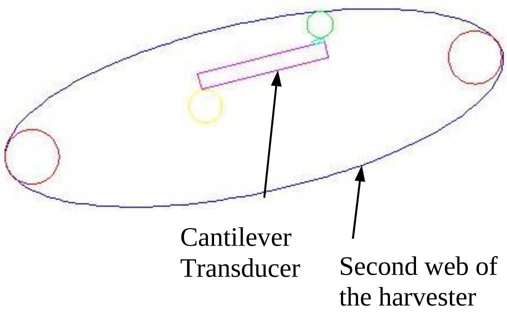


Fig. 3 .Schematic diagram of connecting the load cell to the harvester

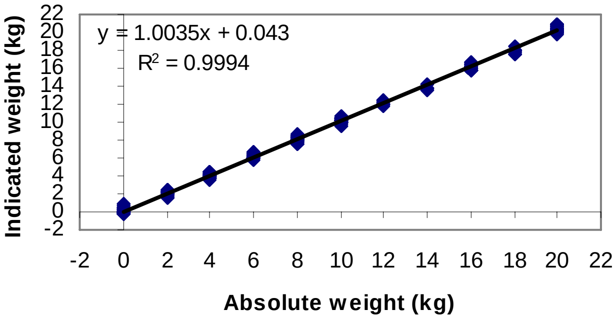


Fig. 4. Correlation between the indicated and absolute weight

2.5 Field Experiments

The field experiments were conducted using the cantilever beams fixed on the second web of the harvester. The signals were sent via the electric board to a laptop computer. The following weight data sets were recorded:

- Empty harvester at the start of harvesting,
- Harvester full of potatoes at the start and end of the recording time,
- Empty harvester after delivering potatoes into the trailer.

The Potato yield was calculated using the Equ. 1 and Equ. 2:

$$Y = (10 \times F) / (w \times V) \quad (1)$$

$$F = W \times S \quad (2)$$

Where:

W = measured mass of products per metre length of the harvester's second web, kg/m.

S = linear speed of second web, m/s

F = mass flow rate of crops, kg/s

V = the harvester's ground speed, m/s

w = width of the second web, m

Y = crop yield, Mg/ha

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 (50 Mg/ha) and low (30 Mg/ha) product yield for both wet and appropriate harvesting soil conditions. Short and long data recording time, such as one, three, five or six minutes, were used to determine and calculate potato yield. Idler wheels with 50 and 125 mm diameter were used in the weighing system to evaluate this influence on the performance of the weighing system. Dirt tare of potatoes were weighed after discharging trailer contains potatoes in dry and wet soil conditions.

2.6 Barn Experiments

Barn studies were organized to evaluate the performance of the load cell supporting system using the harvester. Two transducers were constructed and installed on the harvester in place of two idlers (Fig.5). The position of the transducer was very important to obtain a reliable output signal for products passing over the weighing system.

Static calibrations were performed on the cross conveyor of the 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 putting known weights on the measuring zone while sensing the load which was determined by the weighing system. The calibration procedure was carried out using two different weights (1 to 5 kg) and different conditions on the cross conveyor of the 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 ($0.193 \le L_A \le 0.226$ m). Potatoes were delivered to the harvester using the feeder conveyor, passed over the weighing system and finally collected in a hanging bag, which was weighed using the steelyard. The results are shown in Fig. 6.

Fig. 5. Diagram of the load cell supporting system in the potato harvester

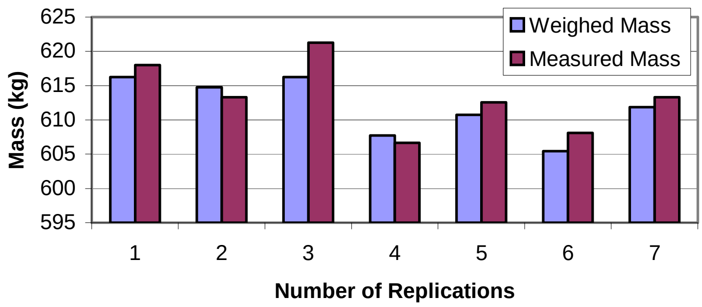


Fig. 6. Data obtained from the measured versus weighed mass

2. RESULTS AND DISCUSSION

The field perturbation experiment was performed to measure the effects arising from extraneous vibration transferred from tractor to the harvester. The results of the dynamic measurement (while 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 results also showed that the average indicated acceleration magnitude, which was transferred from the tractor to the harvester, was less than the calibration level of the 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 eliminate vibration effects due to the high acceleration magnitude. The effect of vibration did not influence the weight measurement systems when an appropriate moving average method was used in the data analysis.

Field studies using the 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 harvester. The installation position was vital to reduce dirt and tare sources such as soil, clods and stones. Two types of idler wheels were used; 50 mm (potato harvester's) and 125 mm equipped with the cantilever beam. The most consistent and precise result was achieved using 125 mm idler wheels connected to the transducers with the lowest mean experimental error of 1.07% of the measured sample yield and the population yield reported by the farmers using the **t** test. Because all the potatoes had an adequate residence time to be stable and weighed without bouncing on the second web of the harvester when they passed over the weighing system, this weight-sensing configuration was the optimum arrangement (Table 1).

Table 1.Results obtained using 125 mm idler wheels connected to the transducers in high yield (12 rep.)

Treatment	Average indicated sample yield (kg/m^2)	Population yield measured by farmer (kg/m^2)	Mean Experimental Error (%)	Sample Variance (kg)	Standard Deviation (kg)
125 mm idler wheels with high yield	5.02	4.984	1.07	0.96	0.98

The moving average was applied based on the working width or distance between two rows (68”/172.7 cm) (Campbell et al. 1994). A 52.6-point moving average 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 reduced the effect of the uneven potato flow on the yield sites (5.02 kg/s for high yield). Dirt tare weight was measured in dry and wet soil conditions. In dry conditions, measured dirt tare weight was 300 kg out of 7916.5 kg, which means that the error was 3.79% whereas in muddy conditions, the dirt tare weight was 1100 kg out of 8977 kg, which means the error was 12.25%. 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 between measured and weighed mass (R^2=0.9994). This was because of the choice of appropriate positions for the load cells underneath the cross conveyor of the harvester. The mean experimental error was 0.57% with a standard deviation of 0.336%. 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.

3. CONCLUSIONS

- The average indicated acceleration magnitude was 2.91 m/s^2, which was less than the calibration level of the acceleration magnitude equal to 3.16 m/s^2 using the accelerometer.
- Field experiments with the commercial 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's arrangement, with an average indicated crop sample yield of 5.02 kg/m^2. This arrangement resulted in the lowest mean experimental error of the sample yield, equal to 1.07%.
- Barn experiments using the harvester showed consistent results using the load cell supporting system. Linear regression analysis between the measured and weighed mass of potatoes was showed R^2 of 0.9994 and a mean experimental error of 0.57%.

4. ACKNOWLEDGEMENTS

Special thanks to Professor R. J. Godwin for his kindly support, advice and help to complete this study and to Professor M. J. O'Dogherty, for his kindly assistance and advice on data analysis and scientific and technical aspects of the dissertation.

5. REFERENCES

Barker, G. L., M. G. Pelletier, J. W. Laird and A. D. Brashears. 2000. Comparison of mass flow rate sensors for ginning stripper-harvested cotton. Applied Engineering in Agriculture. Vol. 16(5): 477-481.

Borgelt, S. C. and K. A.Sudduth. 1992. Grain flow monitoring for in-field yield mapping. ASAE International Summer Meeting, Charlotte, North Carolina.

Caryn, E., B. Ei, M. P. Mailander and R. P. Price. 2001. Sugar Cane Yield Monitoring System. ASAE paper No. 011189. ASAE annual Meeting. Sacramento, California.

Cerri, D. G. an P. G. Magalh. 2005. Sugar Cane Yield Monitor. ASAE paper No. 051154. ASAE annual Meeting. Tampa. Florida.

Demmel, M., and H.Auernhammer. 1999. Local yield measurement in a potato harvester and overall yield pattern in a cereal-potato crop rotation. ASAE St. Joseph, Paper No. 99 11 49

Demmel, M., T. Steinmayr and H. Auernhammer. 1999. Evaluation of local yield detection on a trailed one-row offset lifting bunker-hopper potato harvester. In: Precision Agriculture '99. Sheffield: Sheffield Academic Press, Part 2, pp. 877-886.

Ehlert, D. 2000. Measuring mass flow by bounce plate for yield mapping of potatoes. Precision Agriculture Journal. Springer Netherlands. Vol. 2. No. 2. OCT. 2000. pp. 119-130.

Earl, R., P. N. Wheeler, B. S. Blackmore and R. J. Godwin.1996. Precision farming-the management of variability. Landwards, Winter 1996.

Fisher, S., K. Jaggarad and J. Stafford. 1997. Precision farming for sugar beet. Beet review, VOL. 65 No. 4, 1997.

Fu-ming Lu. 2003. Precision agriculture development in Taiwan. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Vol V. Invited Overview Paper. Presented at the Forum on Bioproduction in East Asia: Technology Development and Opportunities. ASAE Annual meeting, Las Vegas. July 2003.

Godwin, R. J. and P. N. Wheeler. 1997. Yield mapping by mass accumulation rate. ASAE paper No. 97-1061, ASAE, St. Joseph, MI.

Godwin, R. J., P. N. Wheeler, M. J. O'Dogherty, C. D. Watt and T. Richards. 1999. Cumulative mass determination for yield maps of non-grain crops. Computers and Electronics in Agriculture, Elsevier, 23 (1999), 85-101.

Hall, T. L., L. F. Backer, V. L. Hofman and L. J. Smith. 1997. Evaluation of sugar beet yield-sensing systems operating concurrently on a harvester. Department of Agricultural and Biosystems Engineering, North Dakota State University, Fargo, North Dakota.

Hall, T. L., L. F. Backer, V. L. Hofman and L. J. Smith. 2003. Suger beet yield monitoring for site-specific farming Part II-Field testing. Precision Agriculture Journal. Springer Netherlands. Vol. 4. No. 4. DEC. 2003. pp. 433-444.

Kromer, K. H. and P. Degen. 1998. Volume and Scale Based System Measuring Machine Capacity and Yield Soil Tare of Sugar Beet. ASAE paper No. 98-3107, Orlando, Florida.

Kumhala, F., M. Kroulik and V. Prosek. 2003. Dependence of conditioner power input on mowing machine material feed rate. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development: Manuscript PM 02 001. July 2003.

Lee, W. S., J. K. Schueller and T. F. Burks. 2005. Wagon-Based Silage Yield Mapping System. Agricultural Engineering International: the CIGR EJournal. Vol. VII. Manuscript IT 05 003. August, 2005.

Mostofi Sarkari, M. R. 2000. Mass flow rate measurement system for root crop harvesting. PhD Dissertation, Cranfield University- Silsoe- Bedfordshire-MK45 4DT.

Panneton, B. and G. St-Laurent. 1999. Performance of yield monitors for root crops. ASAE paper No. 99-1054, Toronto, Ontario.

Van Canneyt, T. and R. Verschoore. 2000. Yield measurements on a potato harvester.AgEng. Warwick 2000, pp 00-PA-020.

Walter, J. D. and L. F. Backer. 2003. Sugar beet yield monitoring for site-specific farming part I-Laboratory tests and preliminary field tests. Springer Science & Business Media B.V., Formerly Kluwer Academic Publishers B.V. Vol. 4, No. 4, 421 – 431.

Walter, J. D., L. F. Backer, V. L. Hofman and T. F. Scherer. 1996. Sugar beet yield monitoring for site specific farming. ASAE paper No. 96-1022, ASAE, St. Joseph, MI.