RESEARCH PAPER   OPEN ACCESS

Measure grain loss incurred by cleaning unit of a combine harvester with piezoelectric sensors

Adel Taheri[*1], Hossein Navid[1], Javad Robati[2],

[1]Department of Bio system Engineering, University of Tabriz, Tabriz, Iran

[2]Department of Bio System Engineering, Maragheh University, Maragheh, Iran

Key words: Grain loss, Combine, Grain loss, Monitor system, Piezo sensor

Abstract

About 11% of the lands covering Iranian territory are assigned to agriculture, so as to fulfil nutrient needs of about 75% of the Iranian population. Meanwhile, wheat production is seen to enjoy a highlighted position. Within the recent past, a great deal of discussion has been dedicated to the subject matter of wheat loss in the course of the chain from agricultural production to consumption, so as to find solutions for attenuating such a loss, especially in the course of harvesting the crop using combine harvester. Even though some reports indicated such losses to be as much as 20%, the corresponding figures to industrial countries typically range within 2-5%. Grain loss monitoring system is one of the ways to measure the amount of the grain loss in the combine harvesters. The piezoelectric sensors with great sensitivity are usually utilized in this kind of systems. In order to measure grain loss incurred by cleaning unit of a combine harvester, five piezoelectric sensors are used at an approximate spacing of 14cm. TL072 and LM311N were used to amplification of the recorded signal. In order to evaluate the sensor performance, the device was subject to in-lab investigations indicating the best results at the calibration factor (CF) of 5.

*Corresponding Author: Adel Taheri ✉ adel.taheri@yahoo.com

Introduction

There are times in a farm when crop state is as variable as one cannot utilize a combine harvester at its full capacity; on the other hand, there are chances that a combine harvester moves either as slowly as its full capacity is not likely to be realized, or as fast as it generates increased loss rates due overload. As such, it is necessary to be continuously informed about loss rate in a combine harvester, particularly in its separating and cleaning units; this can play a significant role in enhanced combine harvester efficiency. In this case (i.e. when grain loss is continuously monitored), the driver can manage to adjust feed rate with the harvester speed, so as to achieve the desired efficiency. Piezo sensor used to monitor grain loss incurred by cleaning unit of a combine harvester. By installing such a device, one can come to many benefits such as time saving, continuous monitoring of grain loss indices, loss measurement without stopping the combine, an indication of the actual cause of losses, setting the appropriate progress speed, loss control, and the driver's comfort and satisfaction.

Using sensors in agricultural engineering has improved agricultural machines performance and has increased the accuracy, safety and convenience of farm works. Piezo sensor used to monitor grain loss incurred by cleaning unit of a combine harvester. As the most wonderful electrical property of ceramics, piezoelectricity was first discovered in ceramics like barium titanate ($BaTiO_3$) and zirconate titanate (PZT). Piezo refers to pressure, so that, piezoelectricity refers to pressure-derived electricity. Piezoelectric ceramics can convert pressure into electricity and vice versa. Piezoelectricity effect refers to a capability by some materials to transform mechanical energy into electrical energy and vice versa, i.e. the ability to generate electrical potential difference within some nonconductor crystals, such as quartz, under either of tension or compression. The potentials on the two sides of the crystal under compression/tension are equivalent in magnitude, but opposite in direction (sign), with the more tension/compression, the higher potential difference to be generated.

During the past years, several researches were conducted to select appropriate sensing method and design the loss monitor for combine harvesters. Sterlioff *et al.* (1977) used sound characteristics to detect the loosed grains. They installed acoustic sensors at the end of cleaning unit on the rear of harvester, so that an integrated microphone was sensing the sound generated by grains hitting to the sensors. The signals were amplified, filtered and used to calculate grain falling rate.

Eldredge (1985) used piezoelectric sensors to build such a device. A piece of ceramic crystal was firmly attached to separation and cleaning unit of a combine machine. When leaving through the back of combine, the grains fell on the sensor exerting some force on it, so that an electrical signal was generated which was then amplified before the user can employ it to estimate the loss.

Bernhardt and Hubner (2003) presented a novel method, as of that time, together with its implementation, for determining combine harvester grain loss. They equipped different components of separating unit with sonic sensors which generated a signal proportional to the amount of separated crop. The signal was then sent to evaluation unit where it was further processed. Next, a separation curve was established for minimum separation in different units; it was then converted into quantitative properties. Based on the measured quantitative properties, determined grain loss according to the curve was obtained by the evaluation unit. In this approach, since the grain loss was indirectly measured, it was associated with significantly reduced adverse effects of crop changes on grain loss.

Karimi *et al.* (2009) used a load cell to measure grain loss, and aiming to prevent long straws from being fallen on the load cell, they incorporated a mesh into the device. The system design was composed of two parts, namely hardware design and software design. The device was of a high sensitivity which was adjustable in the same time, so that it could identify any loss of down to 50mg weight.

However, due to the large deal of noise signals produced at such a high sensitivity, and also the fact that grain loss was measured in percentages of total crop (i.e. there was no need to such a high sensitivity), the initial sensitivity of the device was set to 0.1g, with a LCD panel used to display load cell output data. Once manufactured, the device was calibrated and then tested in the laboratory. The results indicated the optimum angle for the installation of the device to be 37°.

Zhao *et al.* (2011) invented a loss monitoring device for the separation unit in a rice combine harvester. Used in this research were piezoelectric sensors made of polyvinylidene fluoride (PVDF). The experimental results indicated that, since the grain density was higher than MOG, the corresponding frequency to and magnitude of generated voltage by the grains were likely to be larger. In order to distinguish combine-generated vibrations from signals generated by MOG, the critical frequency was taken within the range of 1-5kHz. The sensor was tested and calibrated in the laboratory. The sensor installation angle and its distance from material falling level were set to 45° and 250mm, respectively. The relative error associated with counting the grains was found to be 4.5%. Continuing with their research, they investigated the sensor while it was operating under farm conditions with the combine progress speed set to 0.8 – 1.2 m/s. The results indicated a relative error of less than 12%.

Zhao *et al.* (2012) presented a loss measuring device for separator unit of a rice combine using piezoelectric sensors (PVDF). In this research the frequency spectrum of vertical acceleration due to the combine body was approximately 3kHz; also, in order to weaken the interaction effect of the combine vibration, a floating stabilizing arm including two separating layers has been designed.

Taheri *et al.* (2016) presented a vibration absorption mechanism for minimizing the effect of harvester vibrations on the performance of grain loss monitoring devices. They conducted laboratory experiments for evaluation mechanism under two

conditions: with oscillated vibration and real vibration measured by Khalilvandi Behroozyar *et al.* (2013). Device was designed and manufactured to examine the performance of the proposed vibration absorption mechanism. In order to practically examine the vibration absorption mechanism using the developed performance evaluation device, the whole system was installed on a combine harvester and operated under various operating conditions. The results indicated that, not only the proposed vibration absorption mechanism exhibits acceptable performance in terms of preventing vibrations from being transmitted from combine harvester body to the sensors incorporated into the grain loss monitoring device, but also performance evaluation device is confirmed to perform properly.

In order to ensure proper operation of crop combine harvesters, the operation should be paused several times during the harvesting, so as to measure grain loss and determine its cause(s). Grain loss depends on combine configurations, material input rate, farm status, and the land conditions. When installed on the back of a combine, "grain loss monitoring" device can determine simultaneous indication of grain loss incurred by the grain separation and cleaning units, while allowing the user to set an optimum progress speed, when moving within the farm, while sticking with an acceptable level of grain loss. The main objective in this research is to design and manufacture a grain loss monitoring device for combine harvesters which can display grain loss in percentage.

Material and methods
Design and Construction
The system design encompasses five units: sensing and vibration absorption unit, signal amplification and processing unit, display unit, data storage unit, and positioning unit.

The sensor unit is primarily to capture a measure lost grains on the back of the combine. The unit is composed of two main components, sensor and frame. Used in this device were LDT1-028K piezoelectric sensors made by Measurement Specialties (USA).

Being multifunctional, these types of sensors are commonly used to measure vibrations and impact. Piezoelectricity effect refers to a capability some materials enjoy in terms of transforming mechanical energy into electrical energy and vice versa; i.e. generation of electrical potential difference within particular non-conductive crystals such as quartz, when subject to tension or compression, is referred to as piezoelectricity. When subject to an impact, piezoelectric sensors produce a voltage of an amount proportional to the intensity of the impact. Knowing that the corresponding range of voltages to the impacts by wheat grains is different from that of straw, the voltage can be amplified and sent to the processor. Five piezoelectric sensors were installed under the frame at approximate distances of 14cm from each other. Consequently, the vibration absorption unit was installed just below the sensor unit which was attached to the combine body solely via the vibration absorber, so as to prevent body vibrations from being transmitted into the sensors.

The frame is designed in such a way to encompass sensors and vibration absorption unit, so as to prevent straw and clash from directly touching sensors or vibration absorber. Manufactured to be of 70×12 ×5cm dimension, the frame was made of 0.5mm thick steel.

Signal amplification and processing unit represents one of the most important components of every electronic system used to manage sensors. The signals received from any type of sensors include some information which are to be extracted out of the signals via signal processing. As the output signal from the piezoelectric sensors was way weak, a TL072 amplifier, as a non-inverting amplifier, was used to undertake initial amplification of the recorded signal. However, LM311N, as a comparator, was used for the sake of final amplification and detection of the desired impact signals.

Each of the sensors incorporated into the grain loss monitoring device was provided with a separate amplification circuit which was powered by a 12 V power source. MC7805 was used as the voltage regulator in the circuit. Further used along the circuit was an 8-bit ATmega16 microcontroller. Being an AVR controller, ATmega16 can be programmed in Basic Programming Language via BASCOM software. According to the program fed into the microcontroller, whenever the voltage amplitude received from the sensor exceeded the predefined threshold for the wheat grain, the microcontroller was to count once and add it to the previous value of count. The commands along each line of the program were executed using a 20MHz LDT4-028K crystal oscillator which produced the required pulses for the microcontroller.

The device was equipped with a TS240128D display mounted on the device box; in order to make it further user-friendly, the display was coupled with a touch screen which added touch functions to the device.

If the device was solely to have an instantaneous measure of grain loss, there would be no need to provide the system with data storage equipment. However, with the user intended to have a general view on grain loss status across the entire farm, there was a need to store the acquired data by the sensor during each operational session. Developed for this purpose was a data storage module including the following main components: an 8-bit ATmega32 microcontroller, a Secure Digital (SD) memory card, a LF33 regulator, an 8 MHz crystal, and a LED. The connection between the microcontroller and memory card was established via a Serial Peripheral Interface (SPI) bus, while the data storage module was connected to signal amplification and processing, and positioning modules via a serial USART bus. The data storage module had three input ports from signal amplification and processing unit, GPS unit, and power unit.

Laboratory Tests
In order to evaluate the designed grain loss monitoring device some experiments were conducted in the lab. The materials moving from harvester output was simulated using an endless belt conveyor. As the conveyor was run at a constant speed, the materials on the conveyor exhibited similar behavior as those leaving the cleaning unit on a combine

harvester. The conveyor speed was set in such a way that we had all materials fallen on the sensing plate within 10 seconds. The device was tested with the default configurations (Table 1).

Table 1. Set of values were considered as default configurations for the parameters.

Parameter		default configuration
mean farm yield (kg/ha)	Y	4000
mean progress speed (km/h)	v	2.5
the combine head width (m)	d	4.5
1000-grain weight for wheat (g)	m	44
display interval (s)	t	5
Maximum acceptable loss (%)	L	1
calibration factor (CF)	a	1

According to the following calculations, it was found that, 1232 g of wheat was harvested per second:

$$4000^{kg}/_{ha} \times 1.1^{ha}/_{hr} = 4400^{kg}/_{hr}$$
$$4400^{kg}/_{hr} \times 0.00028^{hr}/_{sec} \times 1000^{g}/_{kg} = 1232^{g}/_{sec} \quad (1)$$

Each percent of the lost wheat grain within 10 second across the width of the conveyor (which was about one third of the combine's output width) was found to be equivalent to 41 g of wheat.

$$1232^{g}/_{sec} \times 0.33 \times 0.01 \times 10sec = 40.65\ g \quad (2)$$

Based on the information presented in Table 1 while taking Grain/MOG =1, total weight of straw and clash leaving the separating and cleaning unit of the combine harvester was found to be equal to that of the harvested wheat, i.e. 1232kg. Now, assuming that 5% of the MOG leaving the combine harvester is composed of the straw blown out by the cleaning unit of the combine harvester, the following calculations imply that the out-blown straw within 10 second across an equivalent width to that of the conveyor (which was about one third of the combine's output width) was found to be 203g:

$$1232^{g}/_{sec} \times 0.33 \times 0.05 \times 10sec = 203.28\ g \quad (3)$$

Accordingly, 41g of wheat was mixed with 203g of straw, and the mix was distributed across the conveyor.

This experiment was also undertaken in 9 replications with three different calibration factors (1, 3, and 5).

Result and discussion

The demonstrated results by the proposed device are reported in Table 2 and Figure 1. ANOVA test was used to investigate the data obtained for the three calibration factors (Table 3). With the obtained level of significance been below 0.05, significance differences was observed among the three calibration factors.

Table 2. The demonstrated results of Laboratory tests of system.

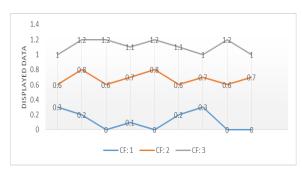| calibration factor (CF)	Data
1	0.2 0.4 0.1 0 0.2 0.3 0.4 0.3 0
3	0.7 1.0 1.1 0.8 0.9 1.1 0.9 0.8 1.0
5	1.4 1.5 1.3 1.5 1.4 1.3 1.5 1.4 1.3

Fig. 1. Laboratory tests of system.

The figure indicated by the device when a mix of wheat and straw is used, is a combined result of the effects of both the grains and straws. According to the observations, the device produced the closest average output value (1.1) to actual loss value (1) when the calibration factor was set to 5. As such, one can suggest that the optimum calibration factor to configure the device is equal to 5.

Regarding the importance borne by the grain loss by the combine harvester when harvesting the crop, a grain loss monitoring device was designed and manufactured to be installed on the cleaning unit of combine harvester. The system design encompassed five units, namely sensing and vibration absorption unit, signal amplification and processing unit, display unit, data storage unit, and positioning unit.

In order to measure grain loss incurred by cleaning unit of a combine harvester, five piezoelectric sensors are used at an approximate spacing of 14cm. In order to evaluate the sensor performance, the device was subject to in-lab investigations indicating the best results at the calibration factor (CF) of 5.

Table 3. Summery and ANOVA Test.

SUMMARY				
Groups	Count	Sum	Average	Variance
CF: 1	9	1.1	0.122222	0.016944
CF: 3	9	6.1	0.677778	0.006944
CF: 5	9	10	1.111111	0.008611
ANOVA				
Source of Variation	SS	df	MS	F	P-value
Between Groups	4.422963	2	2.211481	204.1368	8.5789E-16
Within Groups	0.26	24	0.010833		
Total	4.682963	26			

References

Bernhardt G, Hubner R. 2003. Patent No. 0199291. United States.

Eldredge KW. 1985. Patent No. 4490964. United States.

Karimi H, Navid H, Rostami A, Taheri Hajivand A. 2010. Design and fabrication of grain loss monitoring system in combine. 4th International Conference TAE, (pp. 201-207). Prague.

Khalilvandi Behroozyar S. 2013. Investigation of Combine Harvester Rear Vibration in Different Field Conditions, (MSc Thesis), Department of Agricultural Engineering, Tabriz University, Iran.

Sterlioff WP, Elliott WS, Johnson D. 1972. Patent No. 4036065. United States.

Taheri A, Navid H, Robati J, Rezaie M. 2016. A Performance Evaluation Device for Vibration Absorption Unit of Grain Loss Monitoring Device of Combine Harvester, International Journal of Tropical Agriculture, Vol. 34, No.1.

Zhao Z, Yaoming Li, Jin Chen, Jiaojiao Xu. 2011. Grain separation loss monitoring system in combine harvester, Computers and Electronics in Agriculture **76(2),** pp. 183-188.

Zhao Z, Yaoming Li, Zhenwei Liang, Jin Chen. 2012. Optimum design of grain impact sensor utilizing poly vinylidene fluoride films and a floating raft damping structure, Bio Systems Engineering **112,** 223-227.