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Piezoelectric sensors for combine harvester's grain loss monitor

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Abstract

Using sensors in agricultural engineering has improved agricultural machines performance and has increased the accuracy, safety and convenience of farm works. One of the complex farm machines is grain harvester and evaluate by measuring grain loss. Piezoelectricity effect refers to a capability some materials enjoy in terms of transforming mechanical energy into electrical energy and vice versa. 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 than that of straw, the voltage can be amplified and sent to the processor. In order to measure grain loss incurred by cleaning unit of a combine harvester, five piezoelectric sensors are used at an approximate spacing of 14 cm. 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. The results showed good fitting between the recorded actual data.

Keywords: piezo sensor, amplification, combine harvester, grain Loss

INTRODUCTION

As the most wonderful electrical property of ceramics, piezoelectricity was first discovered in ceramics like barium titanate (BaTiO3) 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

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,

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loss control, and the driver's comfort and satisfaction. 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.

Liu and Leonard (1993) utilized 9 sonic impact sensors arranged in triples below the combine separating unit to build up a combine grain fall measurement device which was able to measure the grain loss simultaneously. Each sensor had its own signal processing and amplification circuits connected to a computer equipped with a micro-processor. The data from different sensors was used to develop a curve describing the way grains were separated in the separating unit; this curve, in turn, was used to infer an exponential loss separation curve in the separating unit. Actual grain loss was then predicted on the basis of this curve. The required hardware and software should be installed on combine harvester.

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.

Maertens et al., (2004) presented a system for separation process monitoring in a combine harvester. The study utilized a CNH CX820 machine which was equipped with two ultrasonic sensors to detect cutting width, a sensor to identify feed rate, two impact sensors below rotational separator, piezo-impact sensors behind straw blowers, piezo-impact sensors at the end of sieves, and a sensor on the returning conveyor. The loss by straw blowers was recognized by impact sensors where grain-generated impacts were separated from those of straws, using the differences in the generated sound, before being counted on a per second basis. In this way, a measure of grain loss in separating unit was obtained. Similar to straw blowers, the cleaning unit was also equipped with impact sensors at its end, i.e. behind the sieves. Using the sensors, the cleaning unit had its loss monitored in a similar way to that of straw blowers (i.e. based in isolating grain- and straw-generated impacts). The signals were transmitted via a control area network (CAN). With this system, measurements were conducted for different feed rates, with the results analyzed to evaluate the system quality.

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 50 mg 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 0.1 g, 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°.

Ni et al., (2011) studied factors affecting the quality provided by sensing elements in a grain loss monitoring device with piezoelectric crystals as its sensors. They found that, the thickness of sensing element represents a way important and effective structural parameter on the recognition of the generated signal by the grain impact. As such, three thicknesses of 0.5, 1.5, and 2.5 mm were investigated in the laboratory, so as to find the optimum thickness for the sensing element. Piezo crystals were attached to four corners of each sensing element before having the crop grains fallen from 30 cm distance above the elements. Accordingly, the optimum thickness for the device to work properly was found to be 1.5 mm.

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 – 5 kHz. 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 250 mm, 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%.

The object of this research was design, prototyping and evaluation of new sensor for measuring grain loss in the rear of grain harvester.

MATERIALS AND METHODS

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 type 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 14 cm 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 × 5 cm dimension, the frame was made of 0.5 mm 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. The final signal amplification circuit is shown in Figure 1.

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.

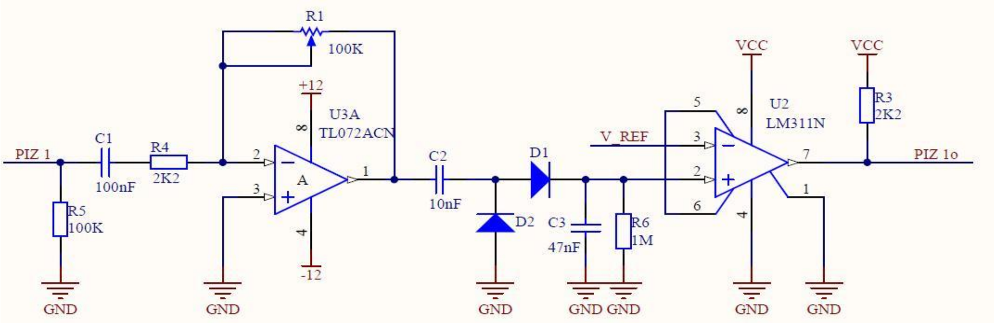

Figure 1. The final signal amplification circuit.

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.

Figure 2 presents an overall view of the presented grain loss control device for combine harvester. A volume controller was provided on the device box to allow for changing the device sensitivity.

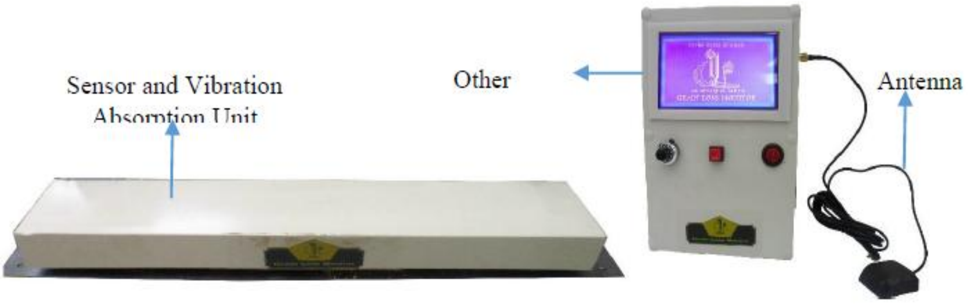

Figure 2. Grain Loss Monitor.

Laboratory Tests and Experimental

In order to evaluate the performance of the presented grain loss monitoring device and simulate the materials as they leave the cleaning unit of a combine harvester, a terminated conveyer was used. 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 (Figure 3). The device was tested with the default configurations (Table 1).

Figure 3. Laboratory tests of system

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:

$$4000\frac{kg}{ha}\times 1.1\frac{ha}{hr}=4400\frac{kg}{hr}$$

$$4400\frac{kg}{hr}\times 0.00028\frac{hr}{sec}\times 1000\frac{g}{kg}=1232\frac{g}{sec} \qquad (1)$$

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.

$$1232\frac{g}{sec}\times 0.33\times 0.01\times 10sec=40.65g \qquad (2)$$

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. 1232 kg. 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 203 g:

$$1232\frac{g}{sec}\times 0.33\times 0.05\times 10sec=203.28g \qquad (3)$$

Accordingly, 41 g of wheat was mixed with 203 g 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). The demonstrated results by the proposed device are reported in Table 2 and Figure 4. 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.

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.

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

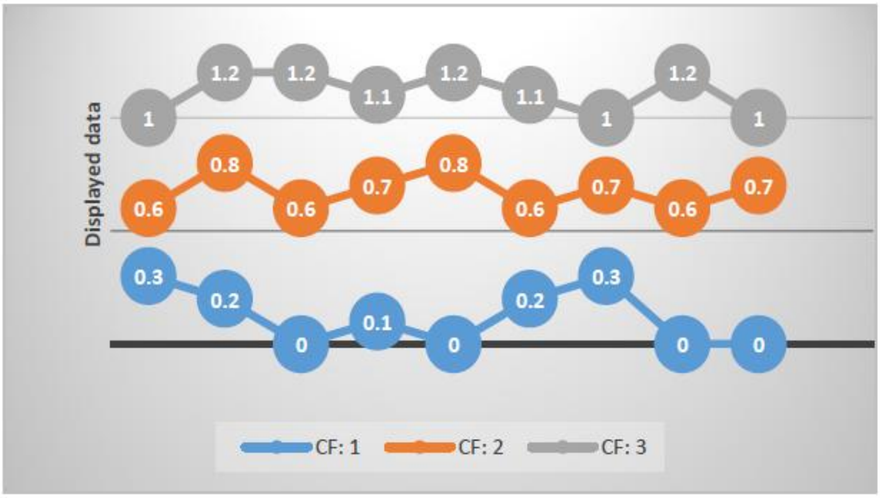

Figure 4. Laboratory tests of system

Table 3: Summery and ANOVA Test

Groups	Count	Sum	Average	Variance	Variance
CF: 1	9	1.1	0.122222	0.016944	0.016944
CF: 3	9	6.1	0.677778	0.006944	0.006944
CF: 5	9	10	1.111111	0.008611	0.008611
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			

CONCLUSIONS

The following conclusions can be drawn from the study:

- 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 14 cm. 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.

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