Design and construction of an automatic coefficient of friction measuring device

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Abstract: The need for knowledge of coefficient of friction of agricultural materials on various surfaces has long been recognized by engineers concerned with rational design of grain bins, silos and other storage structures.   In the design of agricultural machinery, however, the need for this information has been recognized rather recently.   Not finding this information in any handbook or published data, it became necessary to set up a friction test apparatus and obtain the information needed.   We know that the internal friction angle metering devices in our laboratories have the low accuracy, thus we decided to design an automatic internal friction angle metering device with high accuracy which the tangent of this angle is equal to the coefficient of friction that be measured and displayed.   This device is made up of one frame, three hinges, one electromotor with gearbox, one DC Adaptor, one wooden plate that can be changed, acceleration measuring sensor, laser transmitter and LDR for detection of movement, electrical circuit, Microcontroller and monitor for display of the angle and other devices for moving of the wooden plate and carrying of the materials.

1   Introduction

Measuring the physical and mechanical properties of agricultural materials is the most important factor in design and fabrication of machines that is related to the processing of materials.   Among these properties, internal friction and coefficient of friction between materials in designing of machines that is related to handling and displacement of materials has the most important role.   The friction between the granular materials, is the important factor in designing and fabrication of tools that required for processing and handling of them.

The need for knowledge of coefficient of friction of agricultural materials on various surfaces has long been recognized by engineers concerned with rational design of grain bins, silos and other storage structures.   In the design of agricultural machinery, however, the need for this information has been recognized rather recently.   For example, in the design of a chopping and impelling unit, the engineers of a major manufacturer needed some information on the sliding coefficient of friction of chopped alfalfa and corn on steel.   Not finding this information in any handbook or published data, it became necessary to set up a friction test apparatus and obtain the information needed.   Obviously, before granular or unconsolidated materials can flow from a bin by gravity or a loaded auger can be started by a power source, the forces of static friction must be overcome.   Likewise, once the forced flow has begun, the dynamic coefficient of friction is needed before the power requirement for continued flow can be estimated (Mohsenin, 1986).

Mashallah Kermani (1998) ran two separate tests for determination of coefficient of friction of Pea over the steel and galvanized steel sheets. Independent variables were moisture content of product in three levels of 7.5%, 15% and 21% wet basis, sliding velocity in four levels of velocity (5, 20, 100 and 500 mm/min) and normal pressure in three levels of 13.79, 100 and 150 kPa. He reported that moisture content, sliding velocity and normal pressure have significant effects on coefficients of friction between pea and sheets. Overall, with the increasing of moisture content of pea, the coefficient of friction had significant increasing. With the increasing of the sliding velocity (in lower velocities between 5-20 mm/min), the increases in coefficient of friction was observed but in higher sliding velocity (500 mm/min) decreases in coefficient of friction was observed. Also, with the increasing in normal pressure, increases in coefficient of friction was observed.

Amir Aslani (2008) considered the effect of internal friction angle of sediments on dimensions of panning hole resulted from free falling jet. In this study, panning process in downward of free falling jet, was simulated numerically and three dimensionally. Amiraslani used Flow3d software and k-ε standard model in this research. He reported that panning hole with larger in internal friction angle had small length and width and big height or depth.

Emami Najafabadi (2004) studied the aerodynamic and frictional properties of corn silage. In this study, terminal velocity and internal friction angle of silage corn was determined. Emami Najafabadi reported that moisture content and distribution of corn parts and interaction of them had significant effect on terminal velocity at 1% probability level. Emami Najafabadi, also reported that moisture content and bulk density had significant effect on internal friction angle at 1% probability level.

The former conventional apparatus can measure the angle of inclined plate with the horizontal; however, this device has some errors such as visual errors in reading the value of angle from the protractor, vibration and tremor of hand, uneven speed of the wooden plate and etc. (Figure 1).

So in solving these problems, we have constructed the new apparatus that can measure the internal friction angle of agricultural materials and coefficient of friction between the engineering and agricultural materials over the various surfaces automatically with high accuracy.
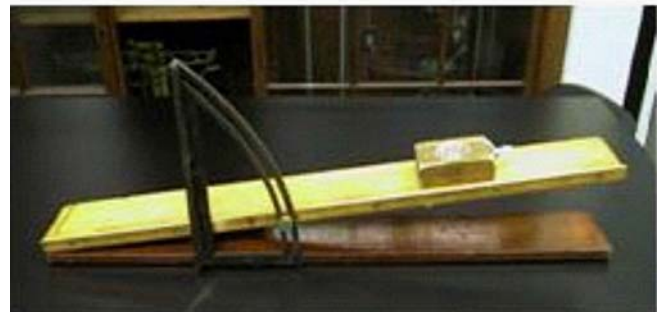

Figure 1   Former conventional apparatus that used for measuring of internal friction angle

2   Materials and methods

For the making of this device, one frame, three hinges (Figure 2), one DC Adaptor (12 V- 2 A), one wooden plate, electromotor with gearbox (its details are shown in Table 1), laser transmitter and LDR for detection of move of the objects on the top of the wooden plate, an AVR microcontroller, one LCD, sensor for measuring of the angle and electrical circuit were needed.
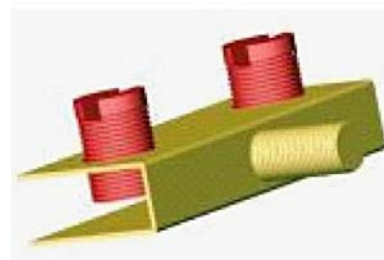

Figure 2   Schematics of the hinge

Table 1   Details of electromotor with gearbox that can be used

Output speed of Motor's shaft/rpm	diameter of gearbox's shaft/mm	Voltage /V	Current /A
50	6	12	0.6

In the beginning of the work a cubic frame from Aluminum with dimensions of 47×24×25 cm was made. Along the upper edge of the frame near the one side we attached the two hinges and then wooden plate mounted on these hinges within the frame. This plate by means of two hinges could move as seesaw. The angle

measurement sensor was mounted beneath the wooden plate that was fixed to the frame by hinges and we could add various surfaces on this plate.

Electromotor mounted on the lower plate within the cubic frame and its output shaft connected to one end of the wooden plate by means of a pulley and wire and the third hinge (Figures 3 and 4). In the end of the electromotor there were 6 contacts, 2 points for intake electricity and 4 points for connecting to the electrical circuits in the display box.

Figure 3   Schematics of the wooden plate and three hinges

Figure 4   View of the frame, electromotor with gearbox, display box and adaptor

An electrical circuit was designed for taking the output data from the sensor and for controlling the motion of the electromotor and wooden plate. For controlling the motion of electromotor we used the AVR microcontroller (Atmega 8). It was inserted in the circuit and inside the display box (Figure 5). The program had two main menus that are measure and setting. In the measure menu there are two submenus; one was auto that was used for auto measuring of the inclined plate angle and the other submenu was manual for manual measuring of the inclined plate angle. In the setting menu there were two submenus; one was sensor setting that was used for setting the angle of the

measuring sensor. This sensor must have a zero angle with horizontal for the accurate measuring. The other submenu was motor speed setting. In this menu we could use the percent of the whole electromotor power such as 60% of whole electromotor power to achieve the lowest vibration and shocking. In the rpm controller driver of electromotor we used two BD139 and two BD140 transistors.

Figure 5   Schematic of display box

For detecting of the materials movement over the wooden plate or other plates, a laser transmitter in one side of wooden plate and LDR receiver in the other side of plate were used (Figure 6). When the object moved from the place between them the delivery light from laser was turned off and at the same time when the LDR was sending the signal to the electrical circuit to stop the motor and measure the inclined plate angle respect to the ground (horizontal), in degree as an internal friction angle of the agricultural materials and the tangent of this angle to two decimal points as a coefficient of friction between the object and the plate (for example between the wheat and wooden plate) and by electrical circuits and AVR microcontroller was displayed on LCD in display box in two rows. For another measurement of internal friction angle we must return the wooden plate to its horizontal location by pushing the Manual LEFT or RIGHT keys on the bottom of the display box. If we want to measure the internal friction angle between agricultural materials and other plates such as steel or glass, we must insert these plates over the wooden plate because the angle measuring sensor was inserted beneath the wooden plate.

For measuring the angle of wooden plate respect to the ground, an ADXL202 sensor was used. This sensor

could measure the acceleration of wooden plate that this acceleration was equal to $g\sin(\theta)$ where g was gravity acceleration and θ was the inclined plate angle and was internal friction angle too (Figure 7). And the static coefficient of friction was equal to $\tan(\theta)$ (Ferdinand et al. 2008; Robert and Marshek, 2006; Vahedian, 1999).
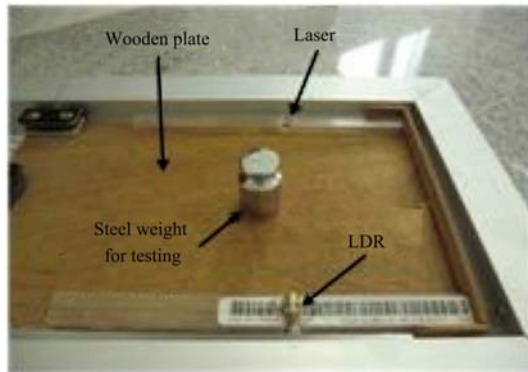

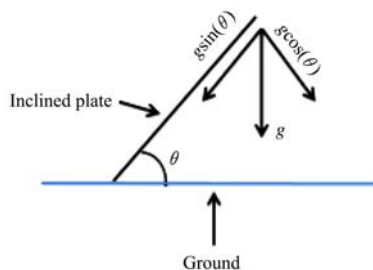Figure 6   Laser and LDR for detection of object movement

Figure 7   The relationship between acceleration components

For measuring the internal friction angle of one material such as wheat, we must put some wheat over the wooden plate and then select the measure menu by pushing the LEFT key on the top of the display box and then by pushing the LEFT key on the top of the display box again to select the Auto measuring (in this stage the RIGHT key on the top of the display box is assigned for selecting the Manual measuring) and then by pushing the OK key for accepting the measuring action. The electromotor was turning on and the wooden plate was allowed to move slowly. When the wheat moved over the wooden plate and the delivery light from laser was turned off, just in this time the LDR was sending the signal to the electrical circuit to stop the motor and measure the inclined plate angle respect to the ground (horizontal), in degree as an internal friction angle of the wheat and the tangent of this angle to two decimal points as a coefficient of friction between the wheat and the wooden plate. These values were displayed in two rows on the LCD in the display box. The manual measuring had low accuracy rather than auto measuring because detection of the motion time and stopping the electromotor were done by eyes and hand, respectively. But all of these actions in the Auto measuring were done automatically.

For evaluation of this device we measured the coefficient of friction of wheat over glass and galvanized steel. The coefficient of friction between wheat and glass was 0.34 and that of wheat over galvanized steel was 0.42 which this agrees with values that reported by Mohsenin (1986). He reported that coefficient of friction of wheat over galvanized steel was in the range of 0.34-0.46. Moisture content of wheat was 15% (wet basis).

3   Conclusions

In the automatic measuring apparatus of the internal friction angle rather than the former conventional device there are some advantages:

1) Measurement accuracy of this apparatus is in the range of one-hundredth of degree while in the former device that was in the range of degree.

2) There is no vibration and tremor but in the former device there was tremor of the operator's hands.

3) There is no error in the recording of the angle of inclined plate but in the former device there was visual error in the reading of the value of angle from the protractor.

4) The value of internal friction angle of agricultural materials in degree is displayed digitally on the LCD in the display box so the time is saved.

5) The value of coefficient of friction between object and surfaces is calculated and displayed digitally and automatically but in the former conventional apparatus we must calculate this parameter by calculator and that is very time-consuming.

6) Doing the experiments with this new device is very easy and convenient but that in the former conventional apparatus is tedious.

7) The results of the measuring of this device agreed with those are reported by Mohsenin (1986).

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