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Measurement Method of the Grain Quantity Based on The Ground Pressure

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Abstract

To measure the stored grain quantity accurately and reliably, the measurement method based on the ground pressure is put forward. According to the randomness of the granary pressure distribution caused by the limited fluidity of the grain, the layout of the pressure on the ground is set up, and the mean pressure on the ground is used to represent the whole ground pressure. At the same time, the pressure distribution on the wall is analyzed and the compensation method is given, which can reduce the sensors used in this method and the cost is low. Lastly, the estimation model of the stored grain quantity based on the ground pressure is put forward, to improve the prediction accuracy of the grain weight, the parameters are estimated based on the ratio of the error. The experiment results shown that, the measurement error is less than 3% by using this method, which can meet the actual need of real-time online monitoring the national grain storage quantity and distribution effectively.

Keywords*: grain quantity, ground pressure, prediction model, parameter estimation*

1. Introduction

The grain is the important strategic resource of our country, which is the foundation of the national economy. Whose quality and quantity is related with the development of the economy and the stabilization of the society directly. But during the grain storage, because of the temperature, moisture and some other man-made factors, the grain quantity will be lossed, which will damage the grain safety [1, 2]. Thus, how to learn the quantity change of the grain accurately real time is the key problem to be solved.

To measure the grain storage quantity real time, many methods have been used, but all these method can't measure the gain weight directetly, the results is not accurate and reliable [3-5]. Thus, the method which mounting some pressure sensors on the ground and the wall according to some regularity is proposed in this paper.

2. The Measurement Principle of the Grain Quantity

Because of the flat granary is mostly often used, thus the pressure distribution of which is researched. In order to measure the quantity of the grain in the barn, the pressure transducer is installed on the ground and wall of the barn. The sensors are even mounted on the ground, and the number is N_1. On the wall, the sensors are installed with equal interval from bottom to top. Supposed that the height of the grain is h, the interval between the adjacent sensors is α, thus, the length and width of the barn is l and w, the friction coefficient between the wall and the grain is μ, according to those parameters, the gross quantity of the grain in the barn can be calculated:

$$G=G_1+G_2 \tag{1}$$

Where G_1 is the grain weight pressed on the ground, G_2 is the grain weight pressed on the wall.

$$G_1=\left(\frac{1}{N_1}\sum_{i=1}^{N_1}q_i\right)\cdot l\cdot w=\bar{q}\cdot A \tag{2}$$

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Where, q_i is the measurement value of the pressure sensor i, $\overline{q}$ is the mean value of all these pressure sensors on the ground, A is the basal area of barn.

$$G_2 = \mu al \sum_{j=1}^{N_2} q_j \quad (3)$$

Where, q_j is the measurement value of the pressure sensor j mounted on the wall, α is the interval between the adjacent sensors, thus:

$$G = \left(\frac{1}{N_1} \sum_{i=1}^{N_1} q_i \right) \cdot l \cdot w + \mu al \sum_{j=1}^{N_2} q_j \quad (4)$$

Based on above equation, if the pressure value q_i, q_j is measured respectively, the gross quantity of the grain G in the barn can be computed. Thus, the key problem is how to measure the pressure value of all these sensors.

3. The Distribution Characteristic of the Pressure on the Ground and Wall

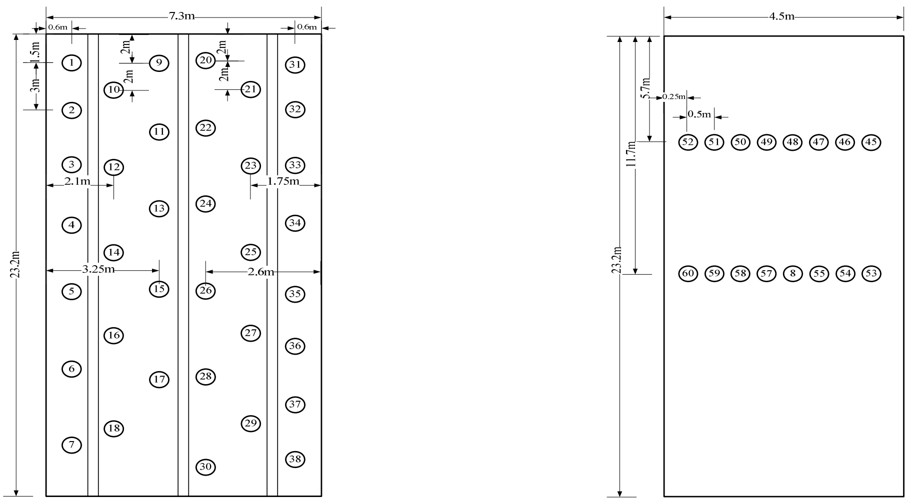
To research the distribution characteristic of the pressure of the barn, the experiment is done at the Liaocheng grain depot in Shandong province, the pressure distribution is analyzed based on the experiment results in the following.

3.1. The Layout of the Pressure Sensor

The size of the barn and the pressure position mounted on the ground and wall are shown in Figure 1, the zoning of the sensor is listed in Table 1.

Table 1. The Zoning of the Pressure

zone	Number of the pressure
B1	1-7
B2	9-18
B3	20-30
B4	31-37
BC	11、13、15、17、22、24、26、28
WL	45-52
WR	8、53-55、57-60



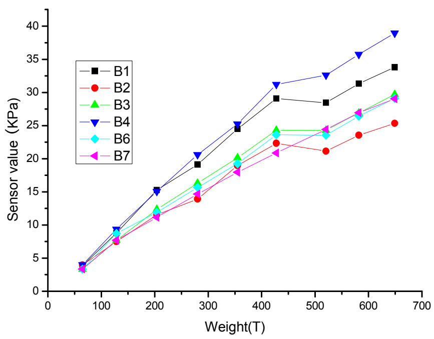
(a) Size and the sensors poison on the ground (b) Size and the sensors poison on the wall

Figure 1. The Size and the Pressure Sensors Poison of the Barn

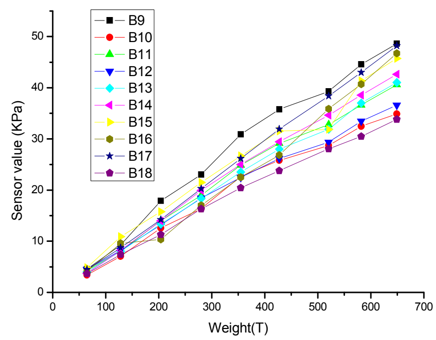
3.2. The Relationship between the Grain Weight and Ground Pressure

The accuracy of the pressure sensor is about 0.5%, and the measurement range is 100KPa, the relationships between the output of pressure sensors in every zone and the loaded grain weight are shown in Figure 2, we can see that, the output of the pressure sensors increasing with the grain quantity raising, because of the limited liquidity of the grain, the pressure on the ground is uneven, and the influence of the wall friction is non-uniform, which induce the output of the sensor is difference and random.

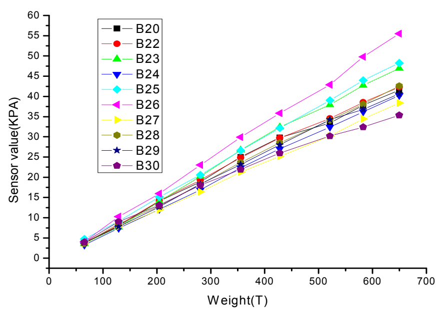
Based on above results, the measurement method of the grain quantity by using the mean value of the sensors mounted in some special zone is put forward, the relationship between the mean value of sensors in three middle areas of the ground and the grain weight is shown in Figure 3. Obviously, compared with the zone B2 and B3, the zone BC is farther from the wall, whose linearity between the pressure and grain weight is better. Thus, to measure the grain quantity accurate, the sensors are better to be mounted at the zone BC.



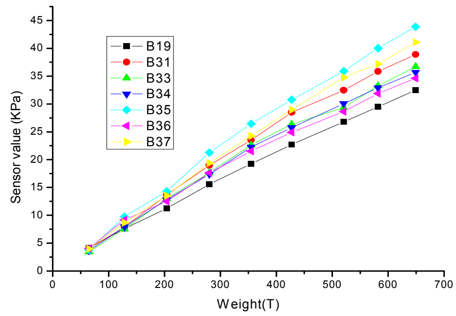
(a) The sensors output of zone B1



(b) The sensors output of zone B2



(c) The sensors output of zone B3



(d) The sensors output of zone B4

Figure 2. The Relationship between the Pressure Sensors of every Zone and the Grain Weight

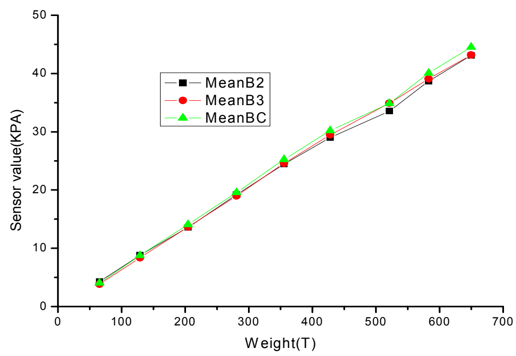
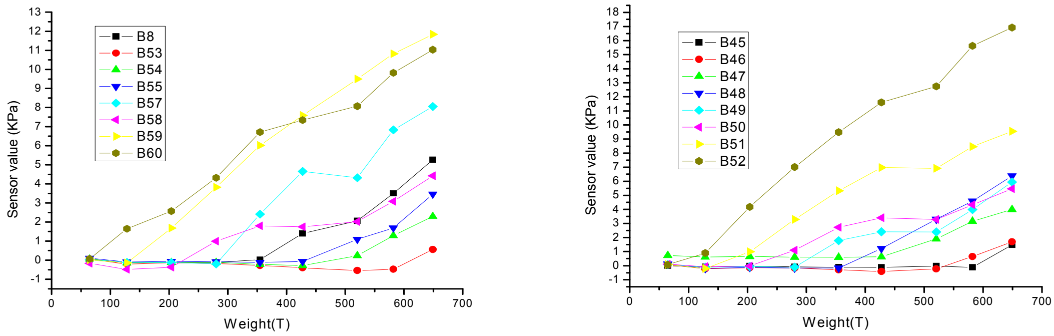


Figure 3. The Relationship between the Mean Value of Sensors in Three Middle Areas of the Ground and the Grain Weight

3.3. The Relationship between the Grain Weight and Wall Pressure

To measure the pressure distribution of the grain on the wall, two columns sensors are mounted on the wall at equal interval, which is shown in Figure1(b). The experiment relationship between the grain weight and the wall pressure of zone WR and WL is shown in Figure 4, from this figure, we can see that: the output of the pressure sensor on the wall is different and random because of the limited fluidity of the grain. And with the raise of the grain height, the friction of wall increases obviously, the ground pressure is affected seriously. Thus, when the grain height is higher, the influence of the friction force must be considered.



(a) The sensors output of zone WR (b) The sensors output of zone WL

Figure 4. The Relationship between the Wall Pressure and the Grain Weight

The friction force of the wall can be calculated by using the layer-by-layer method when the sensors mounted on the wall as Figure1(b). Supposed that the sensor height interval is h, the mean value $\overline{q}(j)$ can be computed at every layer. For example, in the Figure 1(b), the 16 sensors are divided into two columns, each column has 8 sensors, which corresponds to the zone WR and WL, thus there are two sensors s_j^1 and s_j^2 at the layer j, the mean value of layer j can be calculated as $\overline{q}(j) = (q_1(j) + q_2(j))/2$ and the mean friction force of every layer can be computed:

$$\hat{G}_{2j} = \mu h C_B \overline{q(j)} \quad (5)$$

Where, C_B is the perimeter of the barn, h is the height interval of the sensor, μ is friction coefficient. Thus, the friction force is:

$$\hat{G}_2 = \frac{\mu h C_B}{2}\left(\sum_j q(S_j^1) + \sum_j q(S_j^2)\right) \quad (6)$$

The relationship between the output of the wall pressure sensors and the grain weight is shown in Figure 5, where the SumL and SumR is the sum of the pressure values of all the left and right column sensors respectively, MeanSum denotes the mean value of the both, we can see that, the regularity of the SumL and SumR is similar, the relationship between the wall pressure and the grain weight is nonlinear. But the sum of the all pressure on the wall is linear with the square of the mean pressure of the ground, that is:

$$G_2 \propto (\overline{q})^2 \quad (7)$$

Where the $\overline{q}$ is the mean pressure of zone B3, the relationship between the both is shown in Figure 6, which means that, the influence of the wall pressure can be compensated by the ground pressure, thus the sensors on the wall can be removed, and the grain quantity can be measured only by mounting sensors on the ground.

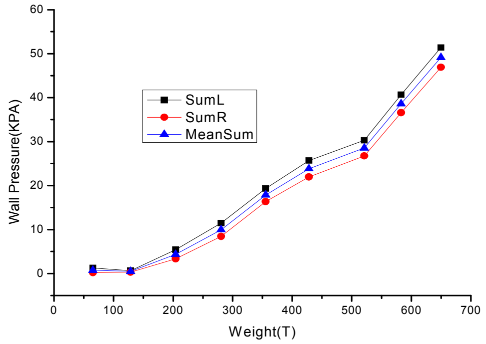


Figure 5. The Relationship between the Grain Weight and the Wall Pressure

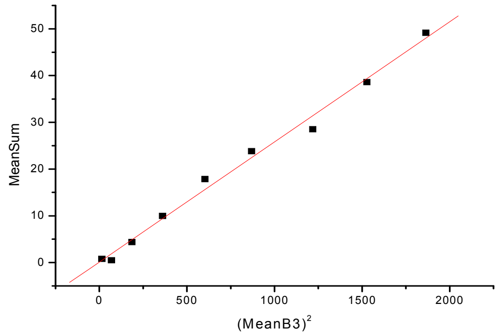


Figure 6. The Relationship between the MeanSum and (Mean B3)^2

4. Parameter Estimation of the Grain Weight Model Based on the Ratio of Error

According to the Figure 2 and Figure 3, we know that, to measure the grain weigh accurately, the sensors on the ground are better to be mounted in the zone B3 and zone BC, thus, the sensors 20, 22, 24, 26, 28 and 30 are only used to measure the ground pressure, the mean value $\bar{q}$ of these six sensors can be computed:

$$\bar{q} = \frac{1}{6}\sum_{6} q_i \tag{8}$$

Where the q_i qi denotes the pressure value of these six sensors. Based on the Figure 6 and Equation (7), the total wall pressure can be expressed by the square of the $\bar{q}$, thus, according to the Equation (1), the grain weight G can be estimated:

$$\hat{G} = A(a_0 + a_1\bar{q} + a_2\bar{q}^2) \tag{9}$$

Where the A is the area of the barn, A=l×w, l and w is the length and width of the barn respectively, a_0, a_1 and a_2 are the parameters of this model. Thus, the key problem which will be resolved is how to get the parameters.

The regression is the conventional method to estimate the parameter [6, 7], the optimized target function of which is:

$$E = \sum_{i}^{n}(G_i - \hat{G}_i)^2 \tag{10}$$

But this method will induce the estimation error is large when the grain weight is small. To resolve this problem, the parameter estimation method based on the ratio of error is put forward, which is:

$$E = \sum_{i=1}^{n}\left(\frac{G_i - \hat{G}_i}{G_i}\right)^2 \tag{11}$$

Where E is the ratio of error, the G_i is the actual loaded grain weight for the sample i, $\hat{G}_i$ is the predicted weight, n is the sample number for model estimation. The Equation (11) can ensure that the optimization target of the model is consistent with the requirement of the grain quantity measurement, and the prediction accuracy can be improved.Substitute the Equation (9) into the Equation (11), we can get:

$$E=\sum_{i=1}^{n}\left(\frac{G_i-a_0-a_1\overline{q}_i-a_2\overline{q}_i^{2}}{G^i}\right)^2 \tag{12}$$

For optimized model described in above equation, to make the E is lest, the parameters of a_0, a_1 and a_2 can be calculated as:

$$a=\mathbf{A}^{-1}\mathbf{B} \tag{13}$$

Where, $a=\begin{bmatrix}a_0\\ a_1.\\ a_2\end{bmatrix}$, $\mathbf{A}=\begin{bmatrix}\sum_i\frac{1}{(G_i)^2} & \sum_i\frac{\overline{q}_i}{(G_i)^2} & \sum_i\frac{\overline{q}_i^{2}}{(G_i)^2}\\ \sum_i\frac{\overline{q}_i}{(G_i)^2} & \sum_i\frac{\overline{q}_i^{2}}{(G_i)^2} & \sum_i\frac{\overline{q}_i^{3}}{(G_i)^2}\\ \sum_i\frac{\overline{q}_i^{2}}{(G_i)^2} & \sum_i\frac{\overline{q}_i^{3}}{(G_i)^2} & \sum_i\frac{\overline{q}_i^{4}}{(G_i)^2}\end{bmatrix}$, $\mathbf{B}=\begin{bmatrix}\sum_i\frac{1}{G_i}\\ \sum_i\frac{\overline{q}_i}{G_i}\\ \sum_i\frac{\overline{q}_i^{2}}{G_i}\end{bmatrix}$

$\overline{q}_i$ is the mean value of the ground pressure for the sample i, which is computed as Equation (8), the $\overline{q}_i^2$, $\overline{q}_i^3$ and $\overline{q}_i^4$ is the square, cubic and quartic of which respectively.

5. Experiment and Analysis

The barn 45# of the Liaocheng grain depot is used to verify this measurement method, the length and width of which is 23.2m and 7.3m, and six sensors are mounted on the ground at the position 20, 22, 24, 26, 28 and 30 as shown in Figure 1, the grain is loaded by divided into 9 times, the data of 4 times are selected to estimate the parameters, the grain weigh and the mean pressure value in every time is shown in Table 2.

Table 2. The Experiment Data

Experiment data in batch		Modeling data	
The loaded grain weight G_i (T)	Mean pressure value on the ground $\overline{q}_i$ (KPa)	The loaded grain weight G_i (T)	Mean pressure value on the ground $\overline{q}_i$ (KPa)
65.29	3.82833	65.29	3.82833
128.82	8.36417	128.82	8.36417
204.402	13.62133	204.402	13.62133
280.729	18.99868	649.69	43.176
355.469	24.563		
427.963	29.471		
521.033	34.901		
582.683	39.079		
649.69	43.176		

Based on these four times data, the model is built by using the conventional regression method which described in Equation (10) is:

$$\hat{G}=A\cdot(0.0705+0.0816\overline{q}+0.00013\overline{q}^2) \tag{14}$$

When using the method based on the ratio of error, which is expressed by Equation (11), the model can be built as:

$$\hat{G}=A\cdot(0.0719+0.0813\overline{q}+0.000135\overline{q}^2) \tag{15}$$

According to above two models, the predicted grain weight and the estimation error is shown in Table 3.

Table 3. The Predicted Results by using Two Kinds Models

The actual loaded grain weight G_i (T)	Predicted results by the regression		Predicted results by the ratio of error	
	Predicted weight $\hat{G}_i$ (T)	Percent of the error (%)	Predicted weight $\hat{G}_i$ (T)	Percent of the error
65.29	65.16959	0.18442	65.26136	0.04387
128.82	129.06601	0.19097	129.0226	0.15728
204.402	204.25936	0.06978	204.10257	0.14649
280.729	282.43302	0.607	282.20856	0.52704
355.469	364.66767	2.58776	364.42452	2.51935
427.963	438.33633	2.42388	438.12	2.37334
521.033	521.07835	0.0087	520.93901	0.01804
582.683	585.62789	0.5054	585.58161	0.49746
649.69	649.67378	0.0025	649.74735	0.00883

Compared the data listed in Table 2, we can see that the mean error is 0.73% and the maximum error is 2.59% for the conventional regression method, but when using the method based on the ratio of error, the mean error is 0.699% and the maximum error is 2.51%, which means that the error is less for the new modeling method. At the same time, when the grain weight is light, the predicted method based on the ratio of error is more reliable.

6. Conclusion

To measure the stored grain quantity accurately and reliably, the method based on the ground pressure is put forward. According to the experiment, the layout of the pressure on the ground is given, and the random of the pressure sensor can be eliminated and compensated by using the ground mean pressure, which can reduce the sensors used in this method and the cost is low. Lastly, to improve the prediction accuracy of the grain weight, the parameters are estimated based on the ratio of the error. The experiment results shown that, the measurement error is less than 3% by using this method, which can meet the measurement requirement of the grain quantity.

Acknowledgements

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