A NOVEL GRAIN LEVEL MEASUREMENT METHOD FOR SILOS

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ABSTRACT

The grain level in a silo is commercially important. In this work, a novel method is presented to detect the grain level in a silo. Existing methods are generally based on approximations, due to grain dust in the silo. The method proposed here eliminates the effect of grain dust and gives the accurate reading of the grain level. The method is based on the measurements of capacitances of parallel plate capacitive structures. The method is mathematically proved to eliminate different factors which affect the readings.

I. INTRODUCTION

Capacitive sensors are used in many applications [1]. Some liquid levels are measured using capacitive sensors [2-4]. Same principle may apply to the grain levels in storage silos. However, these measurements are much more difficult than liquid level measurements; due to dust when pouring grains into the silo, non-homogeneous distribution and low dielectric constants of grains [5]. In case of liquid level in a tank, no dust comes out during the tank filling. However, grains have dust, which diffuses in the air when pouring. This changes the dielectric constant of air considerably. Thus, the readings become faulty and unreliable. The level sensors used in silos are to determine the maximal filling levels [6]. These sensors are unable to measure the current level of grain in the silo at a given time. In a study [7], multiple ultrasonic sensors are used to measure the solid levels.

The other sensors used for liquids are ultrasound sensors, fiber optical sensors. However, these sensors have the following disadvantages for grain measurements [3]: For ultrasound sensors, the system parts should have good acoustic reflection properties. Otherwise, the sound waves are scattered. Also if there are gas bubbles inside the solid, the waves are scattered. The scattering effect and poor acoustic reflection are the main disadvantage of ultrasound sensors in solid level measurements. The grain silos are constructed with wavy material in order to increase load capacity. The wavy nature of the silo walls scatters the sound waves inevitably.

Fiber optical sensors use an optical waveguide. A thin film residue is left on the sensor in case of fluids. This limits the capabilities of the sensor. It has also disadvantages for use in powders, granular substances [3, 8-10].

In case of capacitive sensors, grain level can be measured via changing capacitance due to grain level. However, the factors that affect the sensor reading are various and have a high potential to produce faulty level readings. First of all, the humidity of the grain, the dust in the grain, and the temperature inside the silo, and the type of the grain affect the dielectric constant of the capacitor. All of these factors should be compensated in order to get a reliable level reading. Using only one capacitive sensor cannot eliminate these effects. Therefore, the sensor should be calibrated for every measurement. This is not practical. A solution to this problem is to use two reference capacitors which compensate for all of these factors. It can be shown that this method gives the correct result that is dependent only on the grain level in the silo.

In the next section, the filling technique of silos with grain will briefly be investigated. Then the theoretical details of the level measurement with the proposed method are presented. Following an electronic circuit that can measure the capacitance is given. The conclusions are discussed in the last section.

II. SILO FILLING

Silos are usually filled from the top. First, grains are elevated above the top of the silo by elevators. Then they are carried horizontally in the middle of the silo from top. From that position, the grains are poured inside the silo (Figure 1). Naturally, the dust on the grains becomes free to fly in the air (Figure 1). Normally, the level sensing should be calibrated due to the dielectric constant of air and the grains. The dust in the air changes the dielectric of the air, hence the corresponding capacitance of the unfilled part of the capacitive sensor. Every sensor is prone to the effects of the dust. This results unreliable readings.

III. LEVEL SENSOR ARRANGEMENT

In Figure 2, the sensors are shown schematically in a silo. Two extra capacitive sensors are used. One sensor is placed at the bottom of the silo for grain dielectric reference. The second one is placed at the top of the silo for dusty air dielectric reference. These two sensors are identical with same spatial dimensions. The third sensor is the level sensor placed along the height of the silo. The level is measured by this sensor. All three sensors have the same distance between the parallel plates. Also the width of the plates is same for three of them (Figure 3).

The parallel plates are made from aluminium. The use of parallel plates instead of cylindrical is to allow the grains enter between the plates.

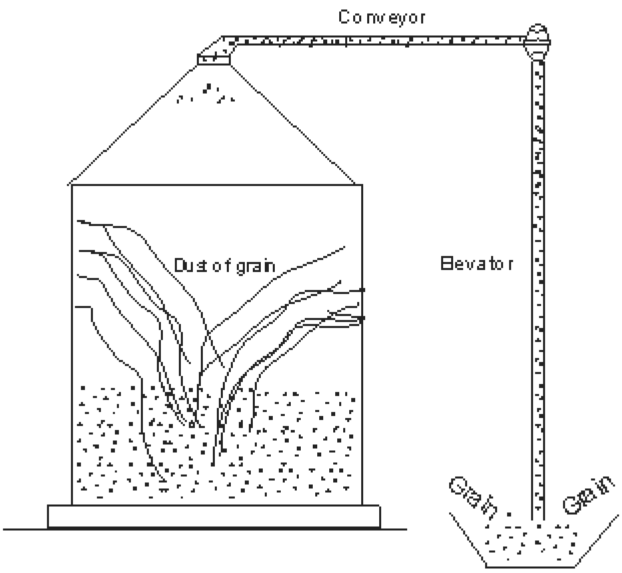

Figure 1 Grain Conveyor and Silo Filling System

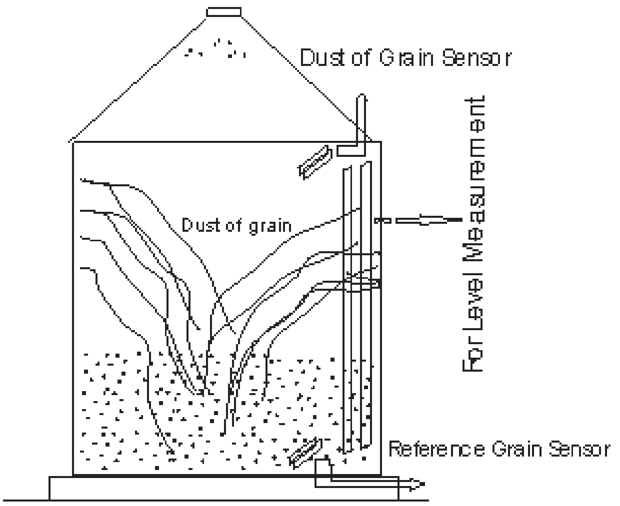

Figure 2 Sensor Setup in the Silo

The dielectric values are converted to digital information by a capacitive to digital converter (CDC) (Figure 4). Here one CDC should be used for each sensor. These CDC's should be placed very close to the sensor in order to reduce the cable loss.

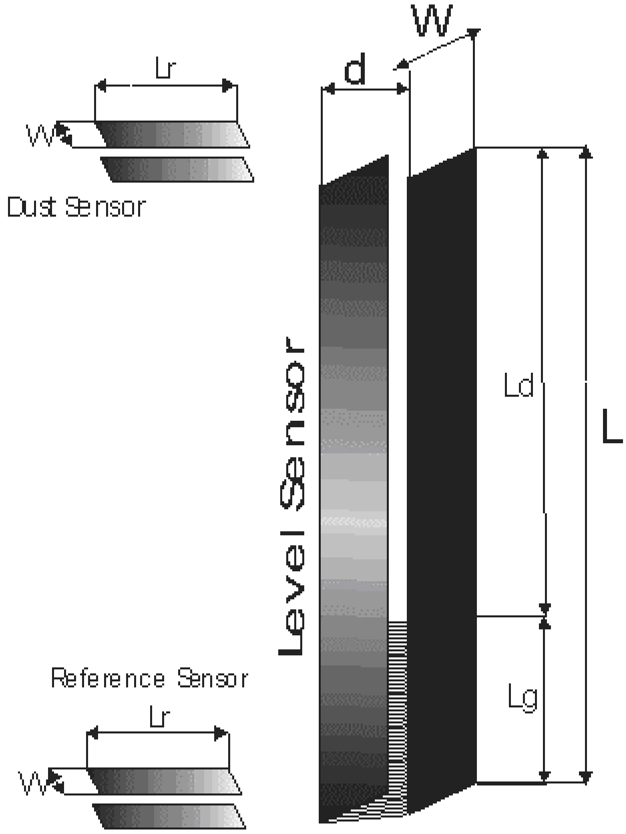

Figure 3 Sensor Dimensions and Setting in the Silo

III. MATHEMATICAL ANALYSIS

The following variables are defined in order to carry the mathematical manipulations:

C_G=Capacitance of grain filled part of the level sensor
C_D=Capacitance of dusty air filled part of the level sensor
C_{LS}=Total capacitance of grain filled level sensor
C_{DS}=Total capacitance of dust sensor
C_{RS}=Total capacitance of grain reference sensor
L=Total length of the level sensor
L_g=Length of grain filled part of the level sensor
L_r=Total length of grain reference and dust sensors
L_d=L–L_g=Length of dust filled part of the level sensor
ε_g=Dielectric constant of grain
ε_d=Dielectric constant of dusty air
W=The width of the sensor plates
d=The distance between the sensor plates

It is easy to write down the following equations for capacitance values [8]:

$$C_G = \frac{\varepsilon_g W L_g}{d} \tag{1}$$

$$C_D = \frac{\varepsilon_d W \left(L - L_g\right)}{d} \tag{2}$$

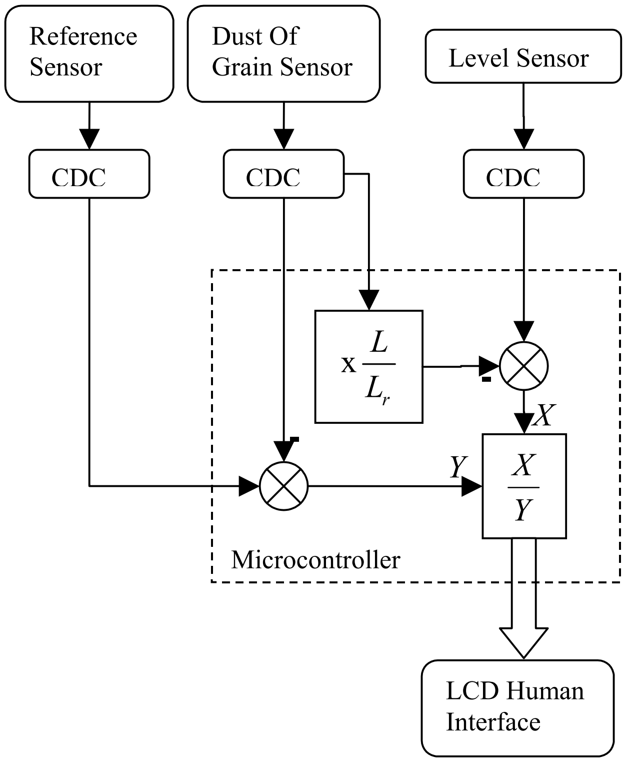

Figure 4 Functional Diagram of Level Measurement

$$C_{LS} = C_G + C_D \tag{3}$$

$$C_{DS} = \frac{\varepsilon_d W L_r}{d} \tag{4}$$

$$C_{RS} = \frac{\varepsilon_g W L_r}{d} \tag{5}$$

The total capacitance of the level sensor if it is supposed to be filled with dusty air can be calculated as follows:

$$C_{LSempty} = \frac{L}{L_r} C_{DS} \tag{6}$$

Let us define the following ratio of the capacitor differences

$$LR = \frac{C_{LS} - C_{LSempty}}{C_{RS} - C_{DS}}. \tag{7}$$

Indeed LR gives the ratio of the length of grain filled part of the level sensor, L_g, and the length of the reference sensor, L_r. This can be shown as follows: The ratio LR in (7) can be written as

$$LR = \frac{\frac{W}{d}\left(\varepsilon_g L_g + \varepsilon_d L - \varepsilon_d L_g\right) - \frac{W}{d}\left(\frac{L}{L_r}\varepsilon_d L_r\right)}{\frac{W}{d}\left(\varepsilon_g L_r\right) - \frac{W}{d}\left(\varepsilon_d L_r\right)}.$$

In the above equations the W/d ratio is cancelled, since it is a factor in every term. Then this yield the following

$$LR = \frac{\varepsilon_g L_g - \varepsilon_d L_g}{\varepsilon_g L_r - \varepsilon_d L_r} = \frac{L_g\left(\varepsilon_g - \varepsilon_d\right)}{L_r\left(\varepsilon_g - \varepsilon_d\right)} = \frac{L_g}{L_r}. \tag{8}$$

Therefore, once LR is obtained, simply it should be multiplied by L_r to get the level of the grain, L_g, in the silo.

The capacitances of the sensors are measured by CDC's and fed to the microcontroller to perform the computations. When the result is obtained, it is immediately sent to the display (Figure 4). There are several digital circuits for this purpose [11]. The CDC circuit is shown in Figure 5. In this circuit, a PIC16F877A microcontroller is used with a capacitance measuring AD7745 integrated circuit. A CDC circuit should be connected to each of the level, grain reference, and dust sensors. It measures the capacitance according to the commands from the main system. The data reading frequency can be adjusted by the main program. To display the result, one of the 2x24 LCD displays of the CDC circuits can be used.

IV. SIMULATION RESULTS AND DISCUSSION

In this study, a capacitive grain level measuring sensor setup is presented. The sensor reading is independent of grain humidity, temperature, dielectric constant, and grain dust in the air. Therefore, the sensor does not require calibration for any of these factors.

These are verified using a simple simulation model. The parameters are assumed to be W=1m, d=0.1m, L_r=1m, L=30m, ε_d=3, r=10m (silo radius). It is assumed that the silo is filled with a constant rate of 1000 kg/s and the grain is distributed uniformly in the horizontal plane of the silo at any given time. Otherwise, a correction factor for nonuniform distribution should be used. The reference sensor is assumed empty in the beginning. Therefore, the reading of the reference sensor is not a constant as in (5) until it is completely filled. The grain filled width W_r of the reference sensor becomes

$$W_r(t) = \begin{cases} L_g(t) & L_g < W \\ W & L_g \geq W \end{cases}. \tag{9}$$

Therefore the C_{RS} expression in (5) should be changed as

$$C_{RS} = \frac{\varepsilon_g W_r L_r}{d} + \frac{\varepsilon_d (W_r - W) L_r}{d}, \tag{10}$$

because it is composed of two parallel capacitors of grain and dust filled parts. Note that, once W_r=W, (10) becomes identical to (5). The propagation of dust through the air will become homogeneous before the reference sensor is filled with grain. Due to this, a homogeneous dust distribution is assumed. The measurement delay is negligible comparing the rate of change of the grain level since the capacitance is measured electronically. The simulation model is exactly the same as in Figure 4, except the input to the level and reference sensors is the output of an integrator, which integrates the constant rate of grain and indicates the grain level. The dust sensor input is a constant. The simulation results for two different grains with dielectric constants ε_g=5 (dry) and ε_g=15 (with some moisture content) are given in Figure 6. The results show that the output of the sensor is independent of grain dielectric constant after (t>2500 sec.) the reference sensor is filled completely with grain and it is exactly equal to the actual grain level. But before the reference sensor is filled with grain completely, readings are erroneous and dependent on physical grain properties. For this period (t<2500 sec. in our case), the readings are unpredictable and should not be used. For small dielectric constant, the readings in the beginning (t<1000sec.) tend to be more accurate (Figure 6). Making the sensor width, *W*, as small as possible will reduce the period of erroneous readings.

V. CONCLUSION

We presented a novel grain level sensor which compensates for grain humidity, temperature, grain type, and grain dust. The result is shown to the user through microcontrollers directly. The use of this sensor will benefit the silo manufacturers, silo owners in order to observe the silo content continuously. Conventional sensors should be calibrated for each type of grain. Also they are affected from grain humidity, temperature, and dust. The designed sensor compensates for all of these factors. We also designed an electronic circuit to process the measurement results (Figure 5). The simulation of the sensor demonstrated that the readings are as predicted by the theory as long as the reference sensor is completely filled with grain. The future work is to implement the sensor and verify the results obtained theoretically.

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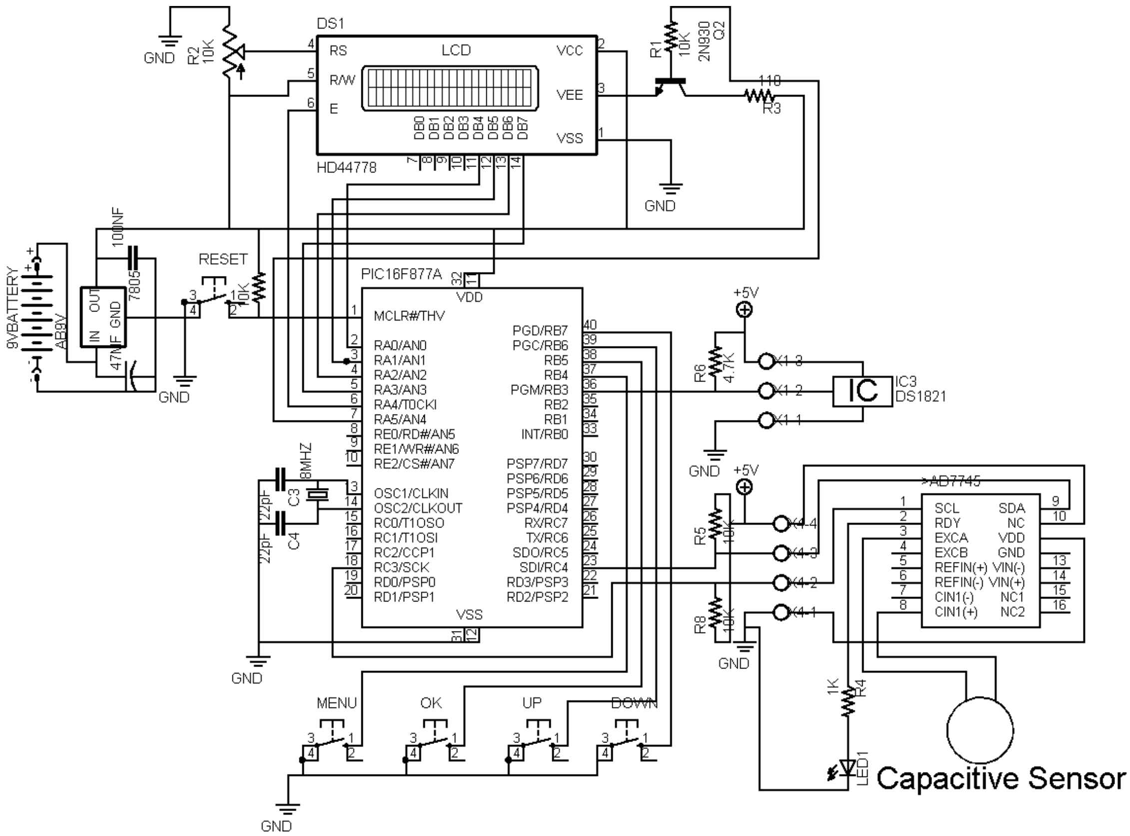

Figure 5 CDC circuit

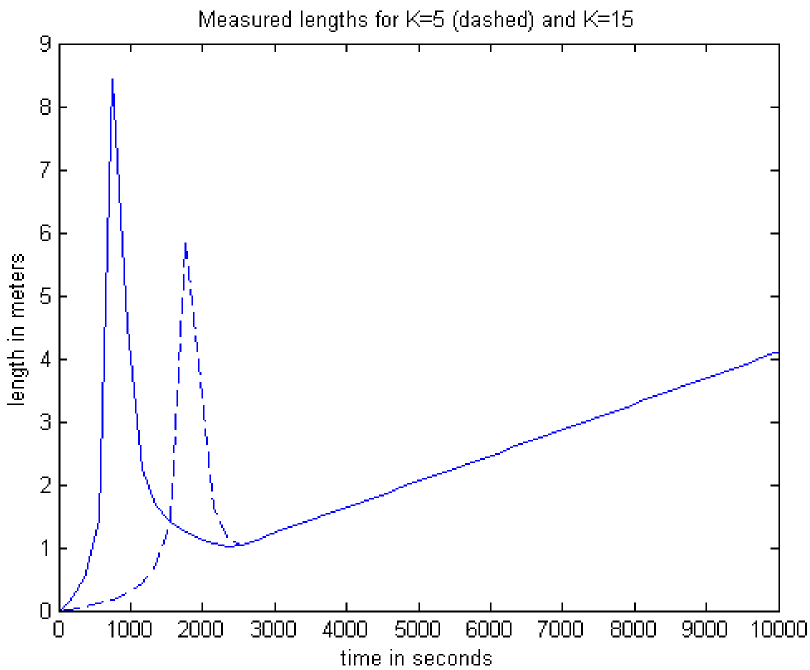

Figure 6 Simulation results for grains with dielectric constants 5 and 15