Design and Fabrication of Silo Level Measurement System

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Abstract— Silos are used to store cement or clinker in cement industries. This silo gets filled and emptied everyday in certain amount. The silo level is required to be recorded on daily basis. By using this silo level, the next day schedule can be made easily. The main objective is to design an automatic system to carry out the cement level measurement in silos. The challenge is to consider behaviour of cement inside the silo as the level does not remain uniform all over the top surface. Many methods are available for silo level measurement such as contact type and non-contact type methods out of which economic and automated method is required to be selected. The main goal of the present project is to design a contact-type weight and cable system to measure the silo level in less time and without human intervention. The proposed design includes mechanical and electronics elements. The report includes a proposed design that will be used to carry out measurement process.

Key words: Encoder, Measurement, Silo

I. INTRODUCTION

A. Preliminary remarks

Cement is a material that exhibit characteristic properties of setting and hardening when mixed to become a paste with water. This makes it into coherent structure to join rigidly. Chemically it is a finely ground mixture having silicates and aluminates which set to a hard mass when treated with water. There are many types of cement such as natural cement, pozzolana cement, slag cement, portland cement [1] etc. Cement is a very important element in any form of construction when used in combination with other ingredients. The cement industry is affected by building and construction activities around the globe. Any construction cannot be developed without use of cement. And as the part of development in construction sector, cement industries tend to increase their productivity with alteration in many conventional processes and with development of automated process. Measurement of silo level is also part of many processes involved in a cement industry. In this project an effort is made to make the silo level measurement process automatic and less time consuming.

B. Silo Level Measurement

Measurement of cement silo level is a crucial task. By measuring the level on daily basis, an estimate can be made for cement production on next day and it also helps to maintain record of production and dispatch of cement for future use. Level measurement for bulk solids like cement is different than for other liquid material because in liquid materials the level remains uniform at all the location on the top surface of the material. For bulk solids which are stored in silos, the distribution of material is not uniform and cone or hip are produced inside the silo. Even taking reading from only one place may not give exact results. There may be a need to get readings from certain locations and have an average reliable value. So, all these factors are needed to be considered while selecting the method to measure cement silo level. Presently, silo level of cement silo is being measured manually. A person climbs up the 30 m silo midnight. The person uses weight and rope for measuring level. The person lowers down the bob through one of the hole available at the top of the silo and as the rope touches cement; the person feels it through his hands by reduced tension in the rope. Then he marks that point on the rope and takes out the rope out of silo. The person measures the length of the marked rope makes an approximation about level of cement in the silo. Basically this job is time consuming and includes labour work. So a new method is to be developed to make the process automatic, less time consuming and even more accurate.

1) Non contact type methods:

Radar, ultrasonic and laser are non contacting type methods available for level measurement. Radar makes use of microwaves. Microwaves are imparted on cement and received by sensor to detect level. But it does not work properly with dusty environment inside the silo and the same method had been used in the plant but was not giving correct results. Ultrasonic method uses ultrasonic waves and it throws these waves on cement and receives back. But it gets scattered with cement particles when flow of cement is running from inlet. Similarly in laser technique also the detection of small laser spot is sometimes difficult to indicate proper level. Thus, non contact type methods were found not suitable for measuring cement silo level accurately.

2) Contact type methods:

Rotating paddle type switches, vibrating type switches and weight and cable are contact type methods available for level measurement. Rotating paddle method consists of a rotating paddle fixed inside the silo which stops rotating when it comes in contact with cement and it sends the signal about indicating level height. Vibrating type switch works on similar principle but it has a vibrating paddle instead of rotating one. Both the above methods have a disadvantage of getting the paddle struck in dusty cement environment after long use. Thus, a weight and cable measurement method was selected to measure silo level automatically. Weight and cable can be used to simply estimate the cement level by lowering the bob inside the silo from the top. Level can be derived by recording the distance from the point where the bob touches the surface to the top of cement silo. It faces the problem of bob getting buried inside cement while measuring. It also requires a person for measurement and recording of data. This process can be made easy if it is automated to some extent by developing a system that does the task without human effort.

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C. Nomenclature

B Barrel diameter
T Traverse distance
U Unused portion
H Used portion
Ty Yield strength
D Diameter of coil d Diameter of wire
F1 Minimum load on spring
F2 Maximum load on spring
G Modulus of rigidity i Number of turns
y Deflection of spring y1 Maximum deflection of spring M Bending moment

II. DESIGN OF SILO LEVEL MEASUREMENT SYSTEM

A. Conceptual design

The level of a cement silo having 4000 ton capacity is to be measured more frequently and automatically in order to get accurate records for estimating next day production. All the available methods for silo level measured measurement were considered and analyzed for the feasibility for the present project. After studying all the methods a design that used weight and cable for measurement process is proposed. The model of the proposed design is prepared in Creo parametric 2.0 software. The proposed design is shown in Figure 1. This design consists of several components such as weight, cable, spool/pulley, spring, swing arm, roller with groove, bush, shaft etc. This whole designed structure is required to be attached to on the top of the silo. The weight of this structure is estimated to be 15 kg after fabrication. It includes metal parts, motor and electronics circuit used for distance measurement.

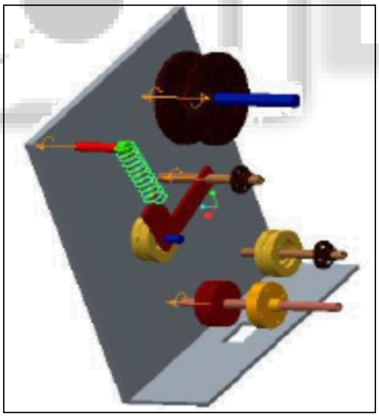

Fig. 1: CAD model of the proposed design

In the design shown in Fig. 2, a spool is directly connected with a DC gear motor. A wire rope is wound on the spool and it has a weight/bob at its end which is hanging inside the silo structure. The wire rope passes through main roller-1 followed by main roller-2 and then it goes towards encoder-roller. Wire rope then rolls towards bottom part inside the silo through holes provided on top of the cement silo. Main roller-1 is fixed at its place and can only roll on the shaft. Main roller-2 is connected with a swing arm. It can roll and move along with swing arm according to movement of spring connected to it. Swing arm is connected with an extension spring which remains in tension in normal condition because of bob hanging inside the silo. As the motor is turned on, the bob inside the silo goes towards bottom of the silo and touches the cement surface which reduces the tension in wire rope and causes swing arm to move upwards due to extension spring force. When arm moves upwards it strikes a limit switch which will cause motor to stop and after certain time the motor will be rotating in reverse direction by getting command from electronic circuit. The length of wire rope w0hichgoes down after initially starting the motor can be calculated using encoder which is connected with one of the shaft of having grooved main roller-2. This reading can be recorded in database and corresponding to this reading, the silo volume can be retrieved on LCD panel.

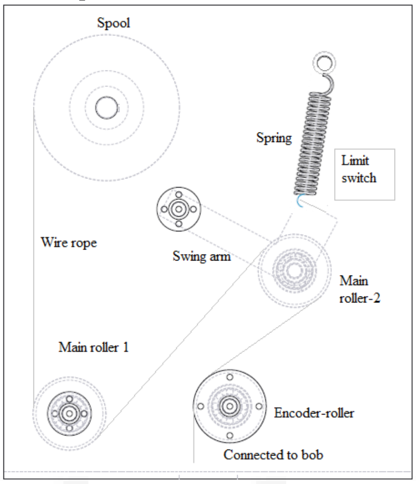

Fig. 2: 2D view of the drawing of the proposed design

B. Components of design

- Bob
- Wire rope
- Pulley/ spool
- Rollers, shafts and swing arm assembly
- Motor
- Spring
- Encoder

1) Bob:

Trials were carried out to see the behaviour of bob inside a truck filled with cement. The bob was brought down inside truck with the help of rope and distance was compared with actual distance between the top of the truck and cement surface .This test was carried out for a pyramid shaped bob made from mild steel and weighing 6.2 kg. The dimensions of the pyramid shape bob are shown. The material used for fabrication was mild steel. As the bob was getting buried inside the cement, same shaped but lighter bob made of mild steel was selected weighing 2.7 kg. This bob gave better results than previous one and was not getting buried inside cement.

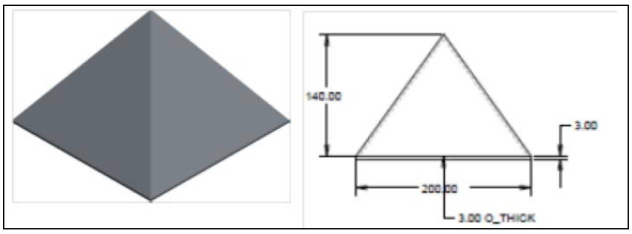

Fig. 3: Drawing and model of the bob used

2) Wire rope:

A rope of 7*7 wire strand results in greater resistance to crushing and strength. Wire rope of 35 m length is used as the total height of silo is 30 m. Table 1 shows safe working load of different size wire ropes. After considering all the size, 2 mm diameter wire rope is selected which has safe working load of 55 kg. Around 4 kg mass is attached at one end of rope and a bit more load will be acting as the bob will of inside the silo. Thus, 2 mm wire rope is a better option for more safety.

Size of wire rope	Mass (kg/100 m)	Safe working load (kg)
1.5	0.9	15
2	1.52	55
3	3.43	108
4	6.1	192
5	9.53	300

Table 1: Strength of wire rope of different size

3) Pulley:

The pulley/spool is a part of the design onto which wire rope will be wound. The material selected for casting of this spool was cast iron. Cast iron is suitable for long time use and will not wear easily. The Figure 2.4 shows a drawing of a spool. Firstly the wire rope diameter is required to be known and that is 2 mm. To know the amount of wire rope that can be wound around the spool, reel factor is required to be calculated. By using trial and error method for different dimensions the final reel factor is calculated as described below. All dimensions must be in inches.

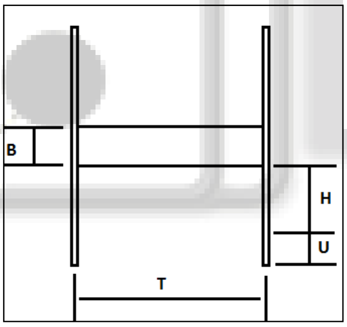

Fig. 4: Diagram of spool

$Reel\ factor = H + B * H * (T) * 0.262$ …...................…..1

For H = 35 mm = 1.3779 inches

B = 30 mm = 1.1811 inches

T = 20 mm = 0.7874 inches

$Reel\ factor = 1.3779 + 1.1811 * 1.3779 * 0.7874 * 0.262$ ....…........................2

= 0.7274

By using this reel factor the approximate maximum length of wire rope is calculated as described below.

$Length\ of\ cable = Reel\ factor/(cable\ diameter)^2$ ...3

= 0.7274/(0.07874)2 $feet$

= 117 $feet$ = 35 m

4) Rollers, shafts and swing arm assembly:

In the proposed design total 3 rollers are required to be used. Two main-rollers are mounted with bearing that will rotate on the shaft and shaft will remain stationary. The outer diameter of the roller is 50 mm and is having 30 mm hole for providing enough space to mount the bearing. Remaining one roller will be used with rotary encoder i.e. Encoder-roller. The encoder-roller is fixed with the shaft rigidly and the shaft is mounted in the vertical plate using bearings. The rotation of encoder-roller will be used to calculate distance as a hollow shaft encoder will be fixed at the end of the corresponding shaft. The encoder-roller is having outer diameter 50 mm and a 10 mm hole for shaft. All the rollers are having a 4 mm groove along their circumference. The rollers are made of cast iron using casting process.

The proposed design includes total 3 shafts. Two shafts are 150 mm long and fixed in the vertical plate. One of the shafts is having a main-roller mounted through bearing and other one is having a swing-arm mounted on it. The remaining i.e. Encoder-shaft shaft is used for encoder and is 220 mm long. Encoder shaft is allowed to rotate freely through the vertical plate with the help of bearings and the encoder-roller is fixed on this shaft. The material used is mild steel for fabricating the shafts.

The basic requirement of swing arm is to operate the limit switch in the design assembly. One end of swing arm is connected to fix shaft and swing arm is allowed to rotate on this shaft axis. The other end is free having a main-roller mounted on it and the extension spring is also connected to the same end to provide rotational movement to it. As the bob will touch cement surface, the tension in rope will get reduced which will cause the swing arm to move upwards so that it will strike limit switch positioned at certain place in order to stop the DC gear motor.

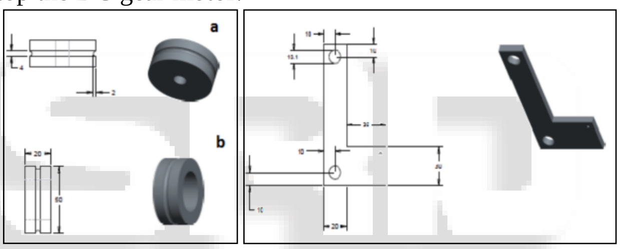

Fig. 5: CAD model of Roller and Swing arm

5) Motor:

Motor is a device that converts electrical energy into mechanical energy. In the proposed design a motor will be used to rotate the spool onto which wire rope will be wound. The rotation of the spool will cause the bob to move upwards or downwards according to requirement. The motor will be selected so that it will be able to sustain the load of the bob (2.7 kg). The motor should be able to rotate in both the direction for upwards and downwards motion. For motor, there are 2 options available i.e. alternating current or direct current motor. Between these two options, direct current motor was selected.

Torque= Force*Distance ….………...……4

Here, force is in Newton and distance is in meter. In the proposed design, weight of the spool is 2.5 kg and the weight of pyramid shaped bob is 2.7 kg. The distance for transferring the motion is considered as 100 mm = 0.1 m.

Total mass = 2.5+2.7

=5.2 kg

Factor of safety is taken as 1.5

Mass =5.2+(5.2/2) ….………..……5

=7.8 kg

=10 kg (By rounding off)

Weight =10*9.81 N

=98.1 N

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The maximum distance from the axis of the motor to apply this force is 100 mm = 0.1 m.

Torque = 98.1*0.1

=9.81 N-m

=10 N-m (By rounding off)

The bob inside the silo is required to move at linear velocity of 0.25m/s. Thus for travelling the distance of 30 m, it will take 120 seconds. Minimum radius to drive wire rope is considered to be 0.15 m.

Velocity= radius*rpm*0.10472…………...6

$$rpm = \frac{velocity}{(radius * 0.10472)}$$

$$= 160\ rpm$$

$$Torque = \frac{Power * 9.554}{rpm} \quad \text{.........................7}$$

$$Power \ = \frac{Torque * rpm}{9.554}$$

$$= \frac{10 * 160}{9.554}$$

$$= 167.46\ watt$$

$$= 180\ watt$$

(For standard size)

$$= 0.25\ HP\ motor$$

Based on these calculations, the specification of the motor is a DC gear motor with 10 N-m torque having 0.25 HP power and 160 rpm.

Fig. 1: Selected motor with drive

6) Spring:

A spring is an elastic object used to store mechanical energy. Springs are elastic bodies (generally metal) that can be twisted, pulled, or stretched by some force. They can return to their original shape when the force is released. In other words it is also termed as a resilient member. A spring is a flexible element used to exert a force or a torque and, at the same time, to store energy. The force can be a linear push or pull, or it can be radial, acting similarly to a rubber band around a roll of drawings. The tension spring is designed based on standard process using basic calculations. Specifications are as follows: 1.5 mm wire diameter, 15 mm outside diameter, 0.5 N/mm stiffness, 175 mm total length.

Fig. 2: Actual spring to be used

7) Encoder:

An encoder is a sensor that generates digital signals in response to mechanical motion. As an electro-mechanical device, an encoder is able to provide motion control system users with information concerning position, velocity and direction. There are two different types of encoders: linear and rotary. A linear encoder responds to motion along a path, while a rotary encoder responds to rotational motion. Based on the requirements, an incremental type hollow shaft encoder was used to convert rotation into distance readings. This encoder is directly connected to encoder roller through a shaft. When wire rope passes through roller it makes the shaft to rotate which in turn makes the connected encoder to rotate. This encoder will give line driver output to controller circuit which will be recorded as reading of the distance up to which silo is empty.

Fig. 8: Hollow shaft encoder

8) Limit switch:

Limit switch is used to operate the motor. When the bob touches the surface of cement, tension in the rope reduces which makes swing arm to move upwards and this movement is used to operate the limit switch which in turn stops the motor. Limit switches are available in different types viz. Roller lever type, Push button type, Inline roller type etc. A roller lever type limit switch of BCH Electric Limited was used which is shown in Figure 9. This switch is having 1 NO (Normally open) and 1 NC (Normally closed) contacts with 24 volts 1 ampere rating.

Fig. 3: Roller lever type limit switch

III. FABRICATION

A. Fabrication

All the components were assembled as per design. After assembling all the parts, whole system was checked and it was made sure that all the parts functioned well. Wire rope was wound on the spool and passed through all rollers as per design. The bob was attached at one end of wire rope so that

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it would hang inside the hole of silo. Motor drive and controller were connected properly with motor. Limit switch, Encoder and through beam sensor were also connected correctly in the circuit.

B. *Testing*

Figure 10 shows the fabricated system placed on the top of the silo. The wire rope gets unwound from spool.

Fig. 4: System fixed on the top of PPC silo

C. *Observation*

Trials were carried out after fixing the system on the top of the PPC silo. Level was measured several times by giving command from quality laboratory. Table 3.1 shows the reading values for measurement. Level readings were also taken by conventional method by using cylindrical bob and rope manually. Table 3.4 shows the difference between readings taken by manual and automatic method. The readings show empty height inside the silo which will be used to get actual weight of the cement with the help of programming. All the readings were taken on the same hole of PPC cement silo for level readings. Result shows that readings with automatic method are comparable to conventional method. Readings with automatic method were in range of +7% difference compared to conventional method.

No.	Conventional (mm)	Automatic (mm)	Difference (%)
1	7450	7126	4.33
2	8820	8263	6.35
3	5231	4902	6.21
4	12252	11910	2.74
5	17652	17355	1.68
6	6905	6774	1.89
7	18542	18240	1.62
8	21157	20784	1.76
9	8994	8651	3.81

Table 2: Level reading of empty cement height

IV. CONCLUSION AND FUTURE SCOPE

A. *Conclusion*

The main objective of the project was to make the level measurement process automatic. The proposed mechanical arrangement can be used successfully to take silo level readings frequently. The system is successfully designed, fabricated, tested and implemented to measure cement silo level. Final results are comparable with conventional method and are in range of 7%.The same system can be fixed on three different holes on the top of silo in order to get combined average silo level reading which will be more accurate than single reading from one hole. Initially, wire rope without any coating was used which caused the problem of the strands getting detached because of twisting. Thus a PVC coated wire rope can be used to avoid this problem. Another problem was about wire rope getting disengaged from the roller. To overcome this, a roller cover can be designed and used to avoid disengagement. In present design there is only one swing arm attached with main roller-2 which caused problem of balancing and the swing arm was getting moved sideways. To overcome this problem, a two swing arm arrangement with a roller fixed in between them can be used in order to get more stable movement. This arrangement can provide cost effective solution with Rs. 35000/- cost for silo level measurement.

B. *Future Scope*

The system designed in this project is able to take reading from one hole only. More accurate reading can be obtained if level measurement is carried out on three different holes on the top of the silo. So instead of fixing three different systems on three holes, some research work can be carried out to make the whole arrangement movable on three holes automatically on the top of silo. If whole system is made movable then it would be easy to get three readings from three holes and an accurate average silo level can be obtained.

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