Control system of the silo aeration process at the cement production

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Abstract. The article developed a control system for the silo aeration process. The object of control is cement silo. Cement silo is a container for storing dry cement, building mixtures or other finely dispersed materials used in the construction or production of building elements for various purposes. The task is to improve the silo control system for cement storage. Recommended ventilation times for aeration sections for commonly used cement silos are presented in terms of silo volume and the amount of material loaded. A silo aeration algorithm was compiled with alarm signals at the operator’s workstation. Four different silo operation modes were compiled to control the storage of material inside the silo: “normal emptying”, “emptying the outer ring sector”, “emptying the chambers”, “complete emptying”. A control program was developed for the cement silage aeration process in the Unity Pro XL program in FBD language.

1. Introduction
For storage of dry concrete mixtures or other bulk materials, specially designed and prepared equipment silo is required.

Silo for cement is a special bunker in which it is possible to store building mixtures, dry cement or other finely dispersed materials. Filling the material into a sealed but ventilated container avoids the risk of reduction and loss of activity when in contact with carbon dioxide and moisture. Of all storage methods, aeration is the most reliable, the product quality remains almost unchanged.

The lack of an algorithm for opening pulse valves for aeration in cement production is an important problem. Air enters the aeration system by opening pulse valves located at the bottom of the silo. Due to the lack of a specific algorithm for opening aeration valves, the raw materials inside the silo will not mix correctly, which will lead to hardening of the cement.

The solution to this problem is to develop a silo aeration process control algorithm and compile four silo operation modes [1].

2. Process description
The air pressure required for aeration of the bottom of the silo is brought to the desired value 0-1000 mbar. Through the shut-off valves figure 1, air is supplied to the corresponding sectors of the bottom requiring aeration. [2] Compressed air pumped through the trough bulk material raises it above the bottom of the silo. The material is fluidized and, supported by the pressure of the entire column of bulk
material, under the action of gravity, flows along inclined troughs from the main silo tank figure 1 into
the troughs of the mixing chamber figure 1.

The appearance of the silo and the location of the air ducts at the bottom of the silo are shown in
figures 1 and 2, respectively.

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**Figure 1.** External image of the mixing silo.

**Figure 2.** Location of aerial chutes at the bottom of the silo.

Figure 2 shows a technological image of the location of the outer ring sector (the location of the
aeration electric valves along the outer contour of the silo bottom 1 (AC) -12 (AC)) and the sector of
free unhindered unloading of material called the camera sector (the location of the aeration electric
valves along the inner contour of the silo bottom 21 - 33).

3. **Description of the algorithm for aeration of the mixing silo**

Silo aeration involves sequential ventilation of the floor sections of the silo.

For section ventilation, only one specific valve must be opened for a given time T1, depending on the
volume of the silo and the amount of loaded raw materials [3].

When switching to the next section, the valves close with a delay of T3 = 2 seconds.

In the event of a valve malfunction (the opening or closing position has not been reached), a signal
is sent to the operator workstation, and this does not lead to the termination of the control process in the
silo.
In case of an error when opening the valve, the valve of the adjacent section automatically opens. In the next ventilation cycle, the open/close signal is not given to the faulty valve until the error that occurred during opening is corrected.

When the ventilation process is interrupted by the operator, the blowers are turned off and the corresponding valves close with a delay of $T_3 = 2$ seconds.

Based on the above criteria, a silo aeration algorithm was compiled figure 3.

4. Operating modes (aeration) of the silo
According to the compiled silo aeration algorithm figure 3, four different silo operation modes were introduced: “normal emptying”, “emptying of the outer ring sector”, “emptying of chambers”, “complete emptying” [4].
If no operating mode is selected from the operator’s automated workstation, the process control device in the silos automatically switches to the “normal emptying” mode.

The full emptying mode can also be selected if the silo is put back into operation after a long period of inactivity, and due to the removal of air from the material, the fluidity of the material remaining in the silo has deteriorated. If the material is particularly sluggish and at the same time prone to sedimentation in the silo, it is recommended to activate the complete emptying program.

Operation mode 1: “normal emptying” [5].

The external and internal sectors are ventilated sequentially, which provides a gradual oxygen saturation of bulk materials inside the silo, and prevents caking and clumping of raw materials.

The ventilation time for each individual section is consistent with the mixing ratio in the silo and is changed by the operator in the executive program, presetting the normal ventilation time $T_1 = 300$ s.

To represent the models of electric shutters, we will represent the camera sector in the form of aeration valves CH 21 –CH 33, the outer ring sector in the form of valves OR 1 –OR 12, and the ventilation time in the form of time variables $T_1$ and $T_2$.

The model of operation of electric valves for aeration in the normal emptying mode is shown in figure 4.

![Figure 4. Model of operation of electric valves for aeration in normal emptying mode.](image)

Operation mode 2: “emptying the outer ring sector”.

Sectors of the outer ring are ventilated in series. Camera sectors are not ventilated. The mode involves forced lifting and subsequent movement of the material under gravity and vortex flows during aeration from the outer ring sector to the camera sector.

The ventilation time for each individual section is consistent with the mixing ratio in the silo and is changed by the operator in the executive program, presetting the normal ventilation time $T_1 = T_2 = 300$ s.

Operation mode 3: “emptying the chambers”.

The camera sectors are ventilated in series. The outer ring sectors are not ventilated. The mode involves the forced movement of material under gravity and vortex flows during aeration from the camera sector to the outer ring sector.

The ventilation time for each individual section is consistent with the mixing ratio in the silo and is changed by the operator in the executive program, presetting the normal ventilation time $T_1 = T_2 = 300$ s.

Operating mode 4: “complete emptying”.

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The camera and outer ring sectors are ventilated at the same time. The mode involves commissioning the silo after a long period of inactivity, or if the material is prone to sedimentation. Also, the mode is used to clean the walls of the silo from residual material, or to check the operation of electric valves.

![Figure 5. Delay time for closing the electric valve.](image)

The ventilation time for each individual section is consistent with the mixing ratio in the silo and is changed by the operator in the control program, presetting the normal ventilation time $T_1=T_2=300$ s.

The delay time for closing the electric shutter for aeration silos of cement is $T_3 = 2$ s. Also, it is possible to force change of this parameter by the operator [6].

The delay time for closing the valve is shown in figure 5.

5. Description of the control program for the plc

To control the process, the ModiconM340 controller was selected. To simulate a silo aeration control system, it is necessary to set the variables of the control program in UnityPro. To implement all 4 specified operating modes in the control system, 64 parameters will be required [7].

Figure 6 shows a fragment of a list of variables in the UnityPro variable editor.

Description of variables used in the program for the controller in Unity Pro:

- CH21-CH33 – control of the opening/closing of electric shutters in the chamber sector during normal emptying mode. The data type is BOOL.
- FCH21-FCH33 – control of the opening/closing of the electric shutters in the chamber sector in the full emptying mode. The data type is BOOL.
- KCH21-KCH33 – control of opening/closing of electric shutters in the chamber sector during the chamber emptying mode. The data type is BOOL.
- OR1-OR12 – control of opening/closing of electric shutters in the sector of the outer ring during normal emptying mode. The data type is BOOL.
- FOR1-FOR12 – control of opening/closing of electric shutters in the sector of the outer ring during the complete emptying mode. The data type is BOOL.
- VOR1-VOR12 – control of opening/closing of electric shutters in the outer ring sector during the emptying of the outer ring. The data type is BOOL.
- T1, T2 – opening time of the electric valve. The data type is TIME.
- T3 – delay time for closing electric valves in the sector. The data type is TIME.

The project is launched by clicking the Connect button in the PLC menu item in Unity Pro [8]. To check the correct operation of the program, we select one of the emptying modes, in this case the normal emptying mode (NORMAL).
6. Conclusion
A silo aeration control system for cement storage has been developed. Recommended ventilation times for outdoor cement silo sectors are presented. The criteria for aeration of cement silo are considered and an aeration algorithm is compiled. According to the compiled silo aeration algorithm, four different silo operation modes were introduced: “normal emptying”, “emptying of the outer ring sector”, “emptying of chambers”, “complete emptying”. The Unity Pro program defines the variables of the control program for the implementation in the control system of all 4 operating modes of aeration of cement silo. The program code in the FBD language for the implementation of the control algorithm for the silo aeration process has been developed.

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