The use of fuzzy logic for the clean-up systems control for bunkers, containing bulk solids

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Abstract. The issues of eliminating the bulk solids overhanging in bunkers using pneumatic pulse devices are considered in the following article. An algorithm for automatic control of pneumatic collapse systems based on the use of fuzzy logic methods is proposed. A constructive solution for this algorithm is given, based on the assessment of the level of bulk material on the conveyor installed at the exit of the hopper. The Mamdani algorithm is used as a fuzzy inference algorithm. The fuzzy Logic Toolbox package of the MATLAB computing environment was used for modeling fuzzy systems. The use of mid-maximum and center-of-gravity methods as a defuzzification method is considered. It is demonstrated that the use of fuzzy logic makes it possible to significantly simplify the development of the control system algorithm.

1. Introduction
In various industries, both domestic and foreign, various bunkers are widely used for storing a variety of bulk solids. The volume of such bunkers allows to place from several liters to thousands of cubic meters of bulk solids. Bunkers are used, for example, for storing flour, fertilizers, ore, etc. They can be arranged both indoors and outdoors. Moreover, in very rare cases, they provide the necessary temperature and humidity conditions; basically, these are natural parameters of the environment.

Depending on the material to be loaded, the size of the bunkers and their shape, and the state of the environment, some of the material may be deposited on the walls of the bunkers due to sticking, freezing, etc., or the material particles may affect each other and form an arch [1]. If a funnel is formed or the material freezes (figure 1), it is possible to stop the material supply from the bunker, which can occur relatively quickly and cause the entire process to stop, even on equipment placed in a warm and dry room. It is necessary to ensure uninterrupted supply of bulk material from the bunker and this is ensured by the use of various systems and devices that provide mechanical shock or vibration effects on the walls of the bunker, as well as pneumatic pulse effects on the material itself placed in the hopper.
Figure 1. Types of bulk solids stagnation in bunkers (a – arch, b – funnel, c – overhanging).

These systems and devices include: vibrators, magnetic pulse systems, and pneumatic pulse systems [2]. Manual cleaning is also used, which is time-consuming and sometimes dangerous. As practice shows, the use of pneumatic pulse devices is less energy-intensive and more effective in combating overhanging in bunkers. The destruction of the bulk materials formed in the bunker occurs due to the impact of compressed air or nitrogen created by the action of a pneumatic pulse device that generates gas pulses. The pneumatic pulse device is filled with compressed gas, and then the accumulated gas is ejected in a fraction of a second, creating a shock effect on the bulk material.

The pneumatic pulse bunker cleaning system is demonstrated in figure 2.

Figure 2. Pneumatic pulse devices mounted on the bunker.

Usually the bunker is equipped with from one to forty pneumatic pulse devices. The number of devices depends on the shape and size of the bunker, as well as on the characteristics of the material being loaded. The efficiency of the system depends largely on the pneumatic pulse devices place of installation. They must be installed in places where the bulk material freezes. Also, much depends on the power of pneumatic pulse devices. When there is insufficient power, the efficiency of using devices drops sharply.
2. The processes of pneumatic pulse destruction of material hangings in bunkers and selection of criteria for evaluating the quality of the processes

The process of stagnant areas pneumatic collapse of the material in the bunker occurs due to the impact of a shock gas wave formed by a pneumatic pulse device on the material. The barrel, through which compressed gas escapes from the pneumatic pulse device, is directed to the place of possible stagnation in the bulk material bunker. After a pneumatic pulse shock, the stagnant zone may collapse immediately or after subsequent impacts. After the destruction of stagnant zones, the material begins to flow to the exit of the bunker.

However, the choice of the possible formation place of overhangings and material arches is made by the service personnel on the basis of existing practical experience in the operation of the equipment.

Most quality criteria for emptying bulk material bunkers are based on several variables [3]. Usually, a graded evaluation of such qualitative variables is performed and used to evaluate the process.

Bunkers (especially small sized), as a rule, do not provide sensors for the level of bulk material in the bunker, and if they are provided, they determine the level of material only in certain places, without giving a complete picture of the overhanging formation. Visual inspection usually does not produce results due to the high dust content inside the bunker.

Therefore, the simplest way to judge the formation of overhanging is by the absence of material at the exit of the bunker. Usually, under the exit, a conveyor is installed, where the material that came out of the bunker is fed to the consumer. According to the amount of material on the conveyor, a conclusion is made about the material leaving the bunker. The amount of material on the conveyor is estimated by the level of material on the conveyor belt using a simple sensor, which is a swinging plate resting on the material on the conveyor. If there is no material on the conveyor, the plate goes down and acts on the sensor. The signal from this sensor indicates that there is no material at the outlet of the bunker.

Control of the level of bulk materials in the bunker is carried out using several sensors, for example, ultrasonic [4]. These sensors can be used to assess the level of the substance in the bunker. The accuracy of the estimation depends on the number of sensors per unit area of the bunker section.

In this way, you can estimate the amount of substance in the bunker and its distribution, but it is difficult to predict the dynamics of emptying. Therefore, the first criterion for evaluating the formation of material stagnation in the bunker after the material exits the bunker is used more often.

The proposed solution is based on the use of a sensor interacting with the plate to control the level of bulk material, similar to the one described above, but having an analog signal at the output for the entire range of plate movement, or monitoring several specific positions of the plate corresponding to specific levels of bulk material on the conveyor (figure 3).

![Figure 3. Types of bulk material sensors on the conveyor (a – using a sensor with an analog converter, b – using a sensor with multiple relay-type converters).](image)

Let us consider using an analog converter. The sensor plate changes its angular position depending on the thickness of the material layer on the conveyor, as a result, the sensor outputs an analog signal, the value of which is proportional to the angle of rotation of the plate and is associated with the thickness of the bulk material layer.
When using multiple relay converters, each of them is adjusted to a specific level of material on the conveyor.

3. Control of bunker cleaning systems using fuzzy logic methods

The control algorithm can be built on the basis of the results obtained by mathematical modeling of the processes of formation of hangings or arches. However, process modeling is a complex task that requires solving a large number of equations together. Solving the problem requires a lot of computing time and resources, and the resulting recommendations can only be presented in a certain range or with a certain probability, and not always high [3].

In many ways, obtaining information to control the processes of collapse of vaults or destruction of hangings by mathematical modeling of the process is inefficient. Recommendations for managing the collapse of hangings and vaults obtained during modeling can only be of a recommendatory nature.

Currently, the most commonly used algorithm is that pneumatic pulse devices start cycling simultaneously or sequentially when there is no material at the outlet of the bunker. This algorithm is easy to implement, but leads to a high consumption of compressed gas, because the system starts working only when a hang or arch has already formed. To increase efficiency, it is necessary to monitor the dynamics of changes in material consumption from the bunker and when there is a pronounced trend of reducing material consumption, it is necessary to turn on pneumatic pulse devices [5].

In this case, it is advisable to use fuzzy logic methods. The sensors demonstrated in figure 3 produce a signal proportional to the thickness of the bulk material layer on the conveyor. If there is no material on the conveyor, the sensor will show the minimum value, and if the layer thickness is close to the maximum – the maximum value. To ensure efficient discharge of bulk material, it is necessary to maintain a large volume of material being discharged per unit of time. This mode of operation corresponds to the maximum reading of the sensor. If the thickness of the material layer on the conveyor decreases, the sensor reading will also decrease, and it is necessary to strengthen the operation of pneumatic pulse devices.

Effective management of this system requires monitoring the dynamics of changes in the thickness of the material on the conveyor. For this purpose, you can install a second sensor located at a certain distance from the first one, or you can do it virtually using a time delay. In this way, you can track the system’s response to the use of air crash systems.

The signal received from the sensor requires fuzzification, i.e. reduction to fuzziness. For the value of the analog signal from the sensor, a linguistic variable is created that contains terms describing the signal strength. The degree of belonging of the received signal to the specified terms is determined by the set membership functions. Then a fuzzy logical output is made using the Mamdani algorithm based on a pre-formed rule base. The database of fuzzy rules is formed on the basis of expert assessments and can be adjusted when new experimental data is obtained. Next, defuzzification is performed using one of the known methods. The choice of defuzzification method depends on many factors and is selected depending on the customer’s needs. After receiving a clear value of the output variable, the pneumatic pulse device generates shock pneumatic signals to eliminate the stagnation of bulk material in the bunker. The system responds to changes in the sensor readings, which ensures uninterrupted unloading of material from the bunker.

Various software packages can be used to create models of fuzzy systems. We use the FuzzyLogicToolbox package of the MATLAB computing environment. The FIS fuzzy output system editor is the main tool for creating and editing fuzzy output systems in graphic mode.

We will develop an algorithm for controlling the pneumatic pulse system for cleaning bunkers for bulk materials based on fuzzy logic. The inputs are the sensor readings and the value of the sensor readings 5 seconds before the current value, which allows tracking the dynamics of changes in the height of the bulk material layer. The values of the sensors are in the range from 0 to 10 V. As an output, we use the duration of the pneumatic pulse and the frequency of their occurrence. However, at the first stage, we will consider the pulse duration constant, since the pulse duration is selected from
the condition of emptying the receiver with compressed gas. Therefore, the output variable will be the
frequency of pneumatic pulses.

Let’s denote the first input variable “Current sensor value”, and the second “Previous sensor
value”. Let’s denote the output variable as “Pneumatic pulse frequency”. After that, the FIS editor
window will look like this (figure 4).

![FIS editor window with input and output variables.](image)

Let’s denote the terms and their membership functions for each of the variables. For the sensor
values, the terms “Low”, “Medium” and “High” are set. For the values of the frequency of pneumatic
pulses, the terms “Absent”, “Low”, “Medium”, “High” and “Maximum” are set.

For the terms “Low” and “High” of the input variables, select the trapezoidal membership
functions with the parameters [0 0 1 4] for the term “Low” and [6 9 10 10] for the term “High”. For
the term “Medium” of input variables, we define a triangular membership function with parameters [2
5 8].

For the terms of the output variable, we define triangular membership functions with the following
parameters: [0 0 6] for the term “Absent”, [0 6 12] for the term “Low”, [6 12 18] for the term
“Average”, [12 18 24] for the term “High”, and [18 24 24] for the term “Maximum”.

Membership functions can be easily adjusted after analyzing the process being implemented.

When creating rules, you should rely on common sense and expert assessments. Let's set the first
rule as if the current sensor value is high and the previous sensor value is high, then the pneumatic
pulse device does not work (the frequency is zero – the term is “Absent”).

Since this system has two input variables, each of which has three terms, it is possible to define
nine unique rules. The resulting rules are shown in table 1 and figure 5.

| Previous value | Low | Medium | High |
|----------------|-----|--------|------|
| Low            | Maximum | High  | Medium |
| Medium         | High  | Medium | Low  |
| High           | Medium | Low   | Absent |

Table 1. Rules for fuzzy inference.
Figure 5. The result of system operation at high (a) and lowered (b) signal levels.

Figure 6. Fuzzy output surface for different membership functions (a, b) and when using the “mom” defuzzification method (c).
After setting all the parameters, we run the modeling. Some of the results obtained are presented in figure 6.

The value of the output variable for the system under consideration, as can be seen from the results, changes unevenly, there are flat sections (figure 6a). By modifying the membership functions of the terms of input variables, you can achieve a smoother change in the output variable (figure 6b). The surface of the fuzzy output is noticeably smoothed, which corresponds to a smoother change in the output variable.

In the surface demonstrated in figures 6a and 6b, the center of gravity method was used as a defuzzification method, which provides smooth control and takes into account all active rules in its operation. However, when using this method, it is not possible to obtain the zero frequency of the pneumatic pulse device.

Using the mid-maximum method allows you to use the entire definition area. The membership functions remain the same (figure 6c), only the defuzzification method changes.

4. Conclusion

The use of fuzzy logic methods allows us to obtain new algorithms for controlling the operation of pneumatic pulse devices. The choice of the defuzzification method and the type of accessory functions depends on the material to be loaded, the shape and size of the bunker, and the customer's requirements. The mid-highs method will provide a great benefit if the pneumatic pulse device rarely works. When the device is operating in a mode that is close to constant, using the center of gravity method will be effective.

Using fuzzy logic allows you to significantly speed up the development of the control system, and also provides tools for fine-tuning the resulting system after conducting pilot tests. The control system determines the desired frequency of operation of pneumatic pulse devices based on the readings of a single level sensor of bulk material on the conveyor installed at the outlet of the bunker. Despite its simplicity, the system can provide high control accuracy and high response speed.

Creating control algorithms based on fuzzy logic is much easier and more demonstrative than traditional methods that use the results of modeling complex mathematical models. Fuzzy logic methods allow getting results that meet the set tasks with significantly less effort.

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