Usage of fuzzy logic for controlling pneumatic caving systems in hoppers in low temperature conditions

V Yu Klyukin, V V Kozhikin, O V Kochneva
Peter the Great St. Petersburg Polytechnic University, Russia

kljukin@mail.ru, tageree@mail.ru, kov_mirny@mail.ru

Abstract. The features of bulk materials hopper storage in the metallurgical and mining industries in the Far North are determined. Possible options for the material hanging, its clumping, and sticking to the walls of the hoppers are indicated. Methods for eliminating the materials hanging in hoppers are examined and their effectiveness is evaluated. In the article it is considered the use of air-impact devices to solve this problem. The process of pneumatic collapse of hangs in the hopper based on these devices is considered. An algorithm for automatic control of pneumatic caving systems based on the use of fuzzy logic methods is proposed. A description of the structural support of this algorithm is given. The solution is based on the use of a sensor that controls the level of material on the conveyor through which material is removed from the hopper. The Mamdani algorithm is used as an algorithm for fuzzy inference. For modeling fuzzy systems was used the Fuzzy Logic Toolbox package of the MATLAB computing environment. The results are presented in the form of graphs and tables and allow take into account the effect of low temperatures on the process of pneumatic collapse. The proposed work algorithm also allows to adapt the accumulated human experience in the management process.

1. Introduction
A lot of minerals are concentrated in the Arctic. A great variety and huge reserves of various minerals and fossil fuels have been discovered in the Arctic territories. Currently, large-scale mining of ores, precious metals, hydrocarbons, precious and semiprecious stones characterize the economies of the Arctic countries.

About 20% of the products needed in the Russian metallurgical and mining industries are mined in the Arctic. For example, in the Murmansk region, with its developed mining industry and metallurgy, are located: the Kola Mining and Metallurgical Company (Norilsk Nickel), Kandalaksha Aluminum Plant (RUSAL OJSC), Olengorsk GOK, Kovdor GOK, Kovdorslyuda, and Apatit OJSC and other enterprises.

The main products of these enterprises are non-ferrous metals, apatiteneferlin ores, complex iron ores, ferrite strontium powders, titanium-magnetite concentrates, iron ore concentrates, apatite concentrates and baddeleyite concentrates and others.

Work in these industries does not stop neither in the heat, nor in the snow or in the cold.

However, the low temperatures that characterize the North impose limitation on production activities, which increase the cost of finished products.

For example, in conditions of low temperatures a large number of hoppers that are used to store ore and finished products, cause great problems for manufacturers. This is due to the fact that particles of
ore, mineral fertilizers or other products can freeze, forming lumps that impede exit of products from the hopper. The supply termination of raw materials from the hopper leads to a halt of the entire production, even if it is organized in warm rooms.

Thus, ensuring the smooth operation of hopper devices is a crucial task, and not only in the North regions.

Depending on the type of material loaded into such hoppers, the temperature and humidity of the environment, the size of the bins and their shape, adhesion may occur. Deposition of the material part to the hopper walls due to adhesion, freezing, etc. Other particles of material can interact with each other to form an arch [1], [2]. Material development can occur relatively quickly. In this case, the following cases may occur, presented in Figure 1. Arching can lead to a complete cessation of the bulk material flow. In the case of a funnel or material hanging-up, the volume of unused material increases.

![Figure 1. Types of stagnation of bulk solids in hoppers](image)

To eliminate the negative impact of material sticking to the hopper walls, the following methods are used: mechanical shock or vibration impact on the walls of the hopper, air-pulse impact on the material, placed in the hopper. The last mentioned method use pneumatic impulse devices (Figure 2) and is more efficient and less energy-intensive, but at low temperatures it is necessary to make higher requirements on the quality of compressed air.
2. Processes of collapse of material hanging-ups in hoppers

Control over the formation of material delays inside the hopper is usually carried out by the presence of material on the conveyor installed under the hopper heat [3]. The lack of material on the conveyor is the basis for the eliminating the causes of the material delay in the hopper. When using automatic control systems for pneumatic impulse devices, the algorithm is usually constructed by time control. This can be a constant actuation of air-pulse devices or actuation only with the absence of material on the output conveyor. In both cases, the flow rate of compressed air or compressed inert gas is significant.

Let’s consider the process of pneumatic collapse of hanging-ups in the hopper based on the use of pneumatic pulse devices.

![Figure 3. Model of pneumatic caving system: 1 – hopper charging chute; 2 – conveyor; 3 – sensor](image)

The trunk of the pneumatic impulse device is directed to the most likely place of the arch formation in the hopper. After the actuation of the pneumatic impulse device, a pneumatic impulse impacts on the hanging material. The destruction of the arch can occur immediately or after a series of “shots”. After the collapse of the arch, the bulk material begins to flow to the conveyor again.

Most assessments of the arch destruction processes quality are based on several variables. Usually a graded assessment of such qualitative variables is performed and it is used to evaluate the process. Most often, the moment of arch formation is recorded by the absence of bulk material in the heat of hopper 1 (Figure 3) (i.e., the material ceases to flow to conveyor 2). In this case, action are taken to destroy the resulting arch. However, at this point, the arch may already be sufficiently compacted and its destruction will require large energy costs.

In the simplest case, the operator carries out the process manually by pressing the manual start button on the control cabinet. In automatic mode, the duration of the pneumatic pulses and their frequency are set.

The trigger criterion in the automatic mode is also the absence of bulk material on the conveyor. However, in contrast to the first case, it is determined not visually but using sensor 3 (Figure 3).

Usually mechanical sensors are used as a sensor. A pivot-hinged plate that slides along bulk materials moving along the conveyor represents them.

When the arch is formed, the material ceases to flow onto the conveyor and the plate drops down and impacts on the sensor. After the arch is destroyed, material appears on the conveyor and the plate
rises - the impact on the sensor ceases. Usually the signal from this sensor determines the moment when the system starts to work in automatic mode.

However, both in the first and in the second case, the system begins to work when an arch of bulk material has already formed.

3. The proposed algorithm for controlling the pneumatic collapse process

The proposed solution is based on using a sensor for monitoring the level of bulk material on the conveyor. The sensor is similar to that described above, but with an analog signal at the output (Figure 4) over the entire range of the plate movements or controlling several specific positions of the plate (Figure 5), corresponding to specific levels of bulk material on conveyor.

![Figure 4. Using a sensor with an analog converter: 1 – an analog converter; 2 – bulk material](image)

![Figure 5. Using a sensor with several relay converters: 1 – relay converters; 2 – bulk material](image)

To control the system, it is proposed to use fuzzy logic. 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 unloading of bulk material, it is required to maintain a large amount of material discharged per unit time. This mode of operation corresponds to the maximum sensor reading. For effective control of the system, it is necessary to monitor the dynamics of changes in the material thickness on the conveyor. For this purpose, a second sensor can be installed at some distance from the first, or it can be done virtually using a time delay. Thus, it is possible to track the response of the system to the use of pneumatic caving systems.

After receiving the signal from the sensor, fuzzification is performed, i.e. reduction to fuzziness. A linguistic variable is created, containing the terms describing the signal level, for the value of the sensor signal. By the given membership functions the degree of belonging of the received signal to the given terms is determined. Then, according to a preformed rule base, a fuzzy inference is made according to the Mamdani algorithm [6], [7], [9]. The base of fuzzy rules is based on expert estimates and can be adjusted when new experimental data is obtained. When forming the rule base, the experience of the operating personnel and the specifics of work in low temperature conditions are taken into account.

After this, defuzzification is performed according to one of the known methods. The choice of defuzzification method depends on many factors and is selected depending on the needs of the customer. After receiving a clear value of the output variable, the pneumatic pulse device generates shock pneumatic signals to eliminate stagnation of bulk material in the hopper. The system responds to changes in sensor readings, which ensures uninterrupted unloading of material from the hopper.
4. Modeling the process of pneumatic collapse

For modeling fuzzy systems, the Fuzzy Logic Toolbox package of the MATLAB computing environment was used [10]. FIS fuzzy inference system editor is the main mean of creating and editing fuzzy inference systems in graphical mode.

The Mamdani algorithm [4], [5] is used as the fuzzy inference algorithm.

The first input variable is “Current Sensor Value” and the second is “Previous Sensor Value”. The output variable is designated as “Pneumatic Pulse Frequency”. After that, the FIS editor window will look as follows (Figure 6).

Figure 6. FIS editor window after adding input and output variables

Next, we define the terms and their membership functions for each of the variables [8]. For the sensor values, the terms “Low”, “Medium” and “High” are set. The terms “None”, “Small”, “Medium”, “High” and “Maximum” are set for the frequency of the pulses.

For the terms “Low” and “High” of the input variables, we choose trapezoidal membership functions with parameters \((0 \ 0 \ 1 \ 4)\) for the term “Low” and \((6 \ 9 \ 10 \ 10)\) for the term “High”. For the term “Average” of input variables, we define a triangular membership function with parameters \((2 \ 5 \ 8)\).

For terms of the output variable, we define triangular membership functions with the following parameters: \([0 \ 0 \ 6]\) for the term “None”, \((0 \ 6 \ 12)\) 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 easily be adjusted after analyzing the actual process. Since this system has two input variables, each of which has three terms, you can set nine unique rules. The resulting rules are shown in table 1.

| Previous | Current | Low | Medium | High |
|----------|---------|-----|--------|------|
| Low      |         |     |        | Medium |
The results are presented in Figures 7, 8, 9.

**Figure 7.** The result of the system at high signal values

**Figure 8.** The result of the system at low signal values

**Figure 9.** Fuzzy inference surface
As shown by Figure 9 the value of the output variable for this system varies unevenly, there are flat sections. By modifying the membership functions of the terms of the input variables, a smoother change in the output variable can be achieved.

5. Conclusion

As a result of the work done, an algorithm for controlling the pneumatic impulse cleaning system of hoppers for bulk materials was developed based on fuzzy logic. Using fuzzy logic can significantly accelerate the development of a control system and provides tools for fine-tuning the resulting system after pilot testing. Despite its simplicity, the system can provide high control accuracy and high response speed.

Creating control algorithms based on fuzzy logic is noticeably easier and more visual for people than traditional methods using complex mathematical models. Often it is simply impossible to create a full-fledged mathematical model for the object that you want to control, while fuzzy logic allows you to get a result that satisfies the requirements with much less effort. Pneumatic caving systems operating in the conditions of the Far North definitely belong to the ones mentioned above.

References

[1] Schulze D 2008 Powders and Bulk Solids. Behavior, Characterization, Storage and Flow Springer: Heidelberg 517
[2] Schulze, D 2016 Storage and Flow of Powders and Bulk Solids Springer-Verlag Particle Technology Series 25 425-478
[3] Siirde A E, Yurkin S V, Yakutov V V 2006 Prevention of fuel hanging with the help of an air-impact knocking system Power Technol Eng 40 357-361
[4] Kruglov V V, Dli M I 2002 Intelligent information systems: computer support for fuzzy logic and fuzzy inference systems Moscow: Fizmatlit (in Russian)
[5] Sandler U, Tsitolovsky L 2008 Neural Cell Behavior and Fuzzy Logic Springer 478
[6] Chernov V. G. 2003 Fuzzy controller. Fundamentals of theory and construction Textbook on the course "Intelligent control systems" (Vladimir: Vladimir state university) 148 (in Russian)
[7] Grigorieva D. R., Gareeva G. A., Basyrov R. R 2018 Fundamentals of fuzzy logic (Naberezhnye Chelny: KFU in Naberezhnye Chelny) 42 (in Russian)
[8] Demidova G. L., Lukichev D. V 2017 Controllers based on fuzzy logic in control systems of technical objects (SPb: ITMO University) 81 (in Russian)
[9] Uskov A. A 2013 Systems with fuzzy models of control objects (Smolensk: Smolensk branch of Russian University of cooperation) 153 (in Russian)
[10] Leonenkov A.V 2005 Fuzzy modeling under MATLAB and fuzzy TECH BHV-Petersburg 736 (in Russian)