Development of automated control systems of sluice gate at mine of second Solikamsky potash-mine department

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Abstract. The article analyzes the statistics of accidents at workplaces of PJSC Uralkali. The mine of the second Solikamsk potash-mine department is the object of the research. Analysis of accidents revealed that fatalities were the results of pinching down by the sluice gate. The devices of the gateway door drive and its electric drive control post have been studied. In order to eliminate accidents related to injuries and deaths of people at the sluice gate, an improved ladder diagram has been developed and recommendations for the installation of additional equipment have been worked out. To describe the graph of sluice gate operation, the necessary logical elements are introduced. The graph of states and transitions of cargo gate control is shown. The use of software and hardware based on the OMRON microcontroller is proposed with the development of a ladder diagram for automation of the sluice gate control system. The safety of miners when working in the mine will be improved as a result of its introduction. It is shown that the failure time in the developed ladder diagram to control the sluice gate motor will be significantly less than in the previously existing scheme.

1. Introduction
As a result of harmful exposure of movers, a mechanic of 5th grade responsible for equipment maintenance and repair was killed. He was pinched by the door of the sluice gate No. 2 of the transport ramp in trunk No. 5 [1]. The motor-reducer of the door drive was mounted on the frame attached to the fixed partition. The drive was a cylindrical motor-reducer 4MTS2S, transmitting motion through an open gear transmission to a rail mounted on the door. The electric motor drive brand was AIR 100L4P3; its power was 4 kW and rotation speed - 1000 rpm. To activate the drive there were push-button control units KU-92 manufactured by JSC VELAN.

2. Equipment and devices used in the studies
In our research we use the OMRON controller and the control panel (Figure 1). In this study we perform OMRON electric drill monitoring and control with the help of CX-Programmer software version 7.1 and CX-Designer [2].

Figure 1. Photo of the operator's touch screen and OMRON controller

3. Results and issues to discuss

To eliminate accidents related to injury and loss of life, a ladder diagram (LD) was developed and the installation of additional equipment at the sluice gate was provided (Figure 2).

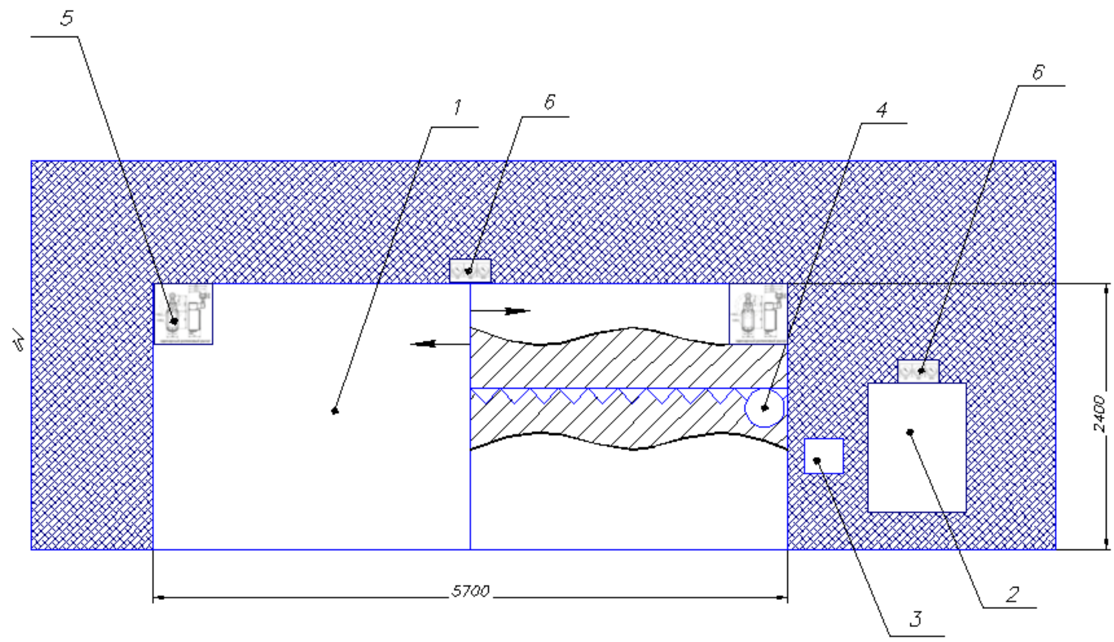


Figure 2. Lock gate scheme: 1 – cargo gate; 2 – hatch for people passage; 3 – control panel and reader; 4 – the electric motor; 5 – limit switch; 6 – motion sensors and magnetic loop

To solve the task, the necessary logical elements were introduced to describe the graph of gate operation (Table 1). Shared access to the mine is allowed by an entry-pass (X0). On the gate there are limit switches (X11) – the sensor "Closed gate" and (X12) – the sensor "Open gate"; the motion sensor (X9) and the sensor "Magnetic loop" (X8). The graph of the states and transitions of the cargo gate control is shown in Figure 3. The gate is closed from the "Open gate" position, and opened from the "Closed gate" position. When the motion sensor and the "Magnetic loop" sensor are activated the motor stops.

Table 1. Designation of logical elements for sluice gate

Variable	Designation	Address	Explanation
X0	PW	I:0.00	Pass Readers, Cargo gate
Y1	Q	100.01	Engine that closes the gate
Y2	Q	100.02	Engine that opens the gate
X8	MLS	I:0.08	Magnetic loop sensor
X9	MS	I:0.09	Motion sensor
X11	Close	1.00	Sensor "Closed gate"
X12	Open	1.01	Sensor "Opened gate"
W5	Manual control	5.00	Release / Close gates

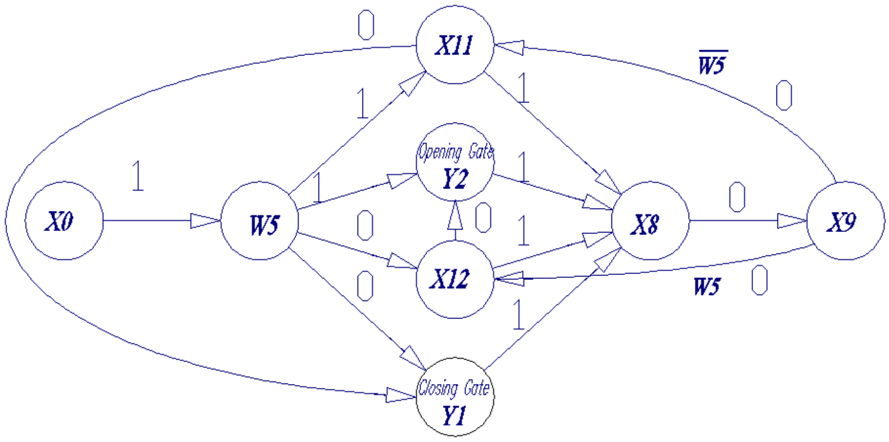


Figure 3. States and transitions graph of a sluice gate control

Figure 4 shows the developed ladder diagram.

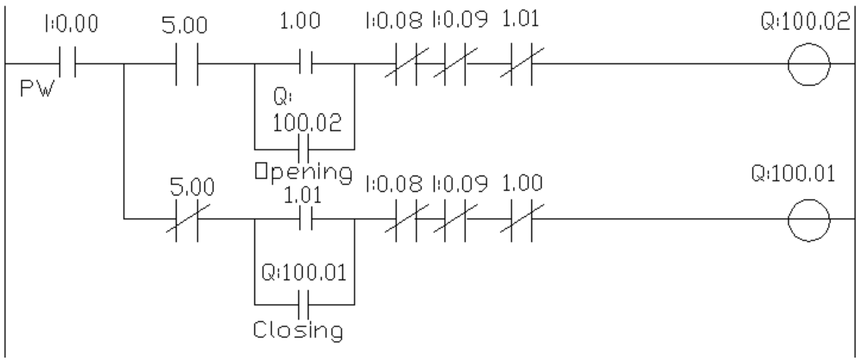


Figure 4. Ladder diagram to control the gate

To meet safety requirements the development of a human-machine imitation system is proposed; it includes the following main parts: the operator's sensor monitor to control the mine access, the set of programs implementing the ladder diagram (LD) [3].

The developed structure of the dialog window for controlling the access system to the mine is shown in Figure 5. The operator's dialog window of access to the mine and control of local facilities for pumping out the filtrate from the SPMD (Solikamsky potash-mine department) – 2 mine contains a duplex control screen (Screen 1) and the access parameters monitoring (Screen 2) (Figure 6). Automated and manual control is provided ("Auto / Manual" button). In automatic mode the system parameters are automatically adjusted according to the algorithm developed. In manual mode the operator controls the installation using the control panel.

Figure 5. Structure of the dialog window to control the access system to the mine

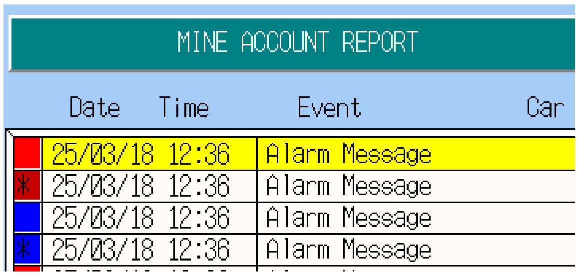
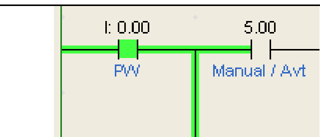
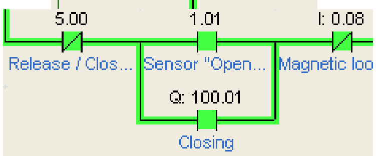
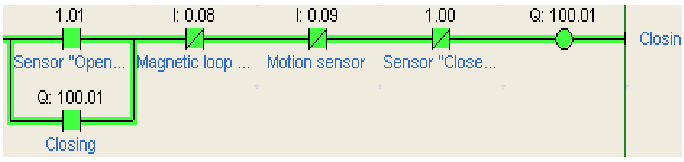
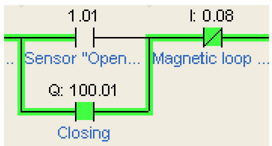
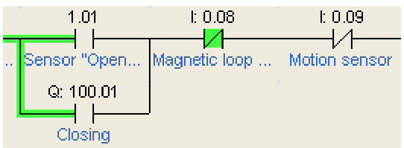
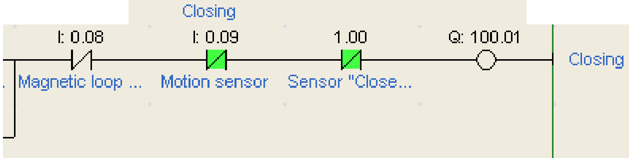
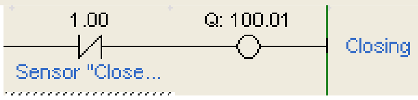


Figure 6. Monitoring of system parameters which establish access to the mine

The operation of the gate control ladder diagram is described in Table 2.

Table 2. Description of operation of the gate control ladder diagram (LD)

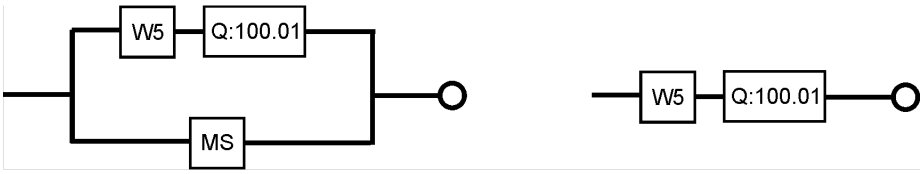
№	Description of work	LD	Operator panel
1	Identification of the pass badge. The reader (PW) receives a value of 1 (If the pass is approached)		
2	Closing the gate (when the switch W5 is turned off "0"), the signal goes along the bottom branch to the closed channel.		
3	off W5 (5,00), the value on the door opening sensor should be 1 (the gate is in the "Open" position), the closing motor (100.01) is triggered, the signal passes through the closed contact (0,08) - DMP, the motion sensor (0,09), and the sensor "Limit switch" closing the gate (Close) → the gate starts to close		
4	The gate moved away from the extreme open position. The final sensor of the "Gate Open" (Open) opened, the current to the motor runs through a blockage		
5	The "Motion sensor" (MS) triggered, the gate stops		
6	The "Magnetic loop sensor" (MLS) triggered, the gate stops		
7	The "Final Sensor" (Close)) is in the extreme closed position, the gate stops		

The effect of component malfunction on the failure of the LD is shown in Table 3.

Table 3. Effect of component malfunction on LD failure

Component	Failure
Button Contact «W5»	Random presses
Button Contacts «W5», «Q:100.01» or sensor «MS»	Sensor mechanical damage

To calculate the probability of trouble-free operation of the system, the structural diagram of the connection of control contacts and sensors should be presented in an equivalent form (Figure 7).



M = (W5 Λ Q:100.01) ∨ MS M = W5 Λ Q:100.01

a b

Figure 7. Schemes for calculating the probability of failure-free operation of the gate motor control system: a – a circuit with the presence of a motion sensor (VDD); b – simplified ladder diagram, which exists in Solikamsk where the accidents took place.

In a system with a sequential structure, the failure of any component results in the failure of the system as a whole; and in a system with a parallel structure the failure of the system as a whole occurs only when all elements fail. The probability of failure-free operation of the existing circuit (Figure 7, b) will be calculated from the successive structure according to formula (1):

$$P_b(t_0) = P_{W5}(t_0) P_Q(t_0). \quad (1)$$

If we assume that all system components have the same exponential distribution of the operating time to failure with a failure rate parameter λ = 0.0005 1 / h, we calculate the time of failure-free operation for 1000 h in the unloaded mode of operation according to formula (2) [4]:

$$(1 + k\lambda t_0) e^{-k\lambda t_0}, \quad (2)$$

where k is the number of elements.

From this we get: $P_{W5}(1000) = P_Q(1000) = P_{MS}(1000) = (1 + 2 \cdot 0{,}0005 \cdot 1000) e^{-2 \cdot 0{,}00005 \cdot 1000} = 0{,}8.$

Then the P_{CC} (1000) = 0.8 · 0.8 = 0.64.

The probability of failure-free operation of the circuit (Figura 7,a) will be calculated using a redundant system:

$$P_a(t_0) = 1 - \prod_{i=1}^{N} (1 - p_i(t_0)), \quad (3)$$

where $p_i(t_0)$ is the probability of failure-free operation of the *i-th* element.

Then $P_a(1000) = 1 - (1 - P_{MS}(1000))(1 - P_b(1000)) = 1 - (1 - 0{,}8)(1 - 0{,}64) = 0{,}928.$

Thus, the probability of reliable operation of LD with the movement sensor is much higher than in the previously existing scheme. The introduction of this automated system will contribute to the safety and security of miners and reduce heavy accidents in the mine.

Conclusion

The article describes a number of models to control the access system to the mine to ensure the safety of miners. The general ladder diagram and control algorithms for the sluice gate have been developed to handle the applied problems of securing the operation of the SPMD (Solikamsky potash-mine department) – 2 mines. In the furtherance of this goal, the following problems have been solved: analysis of working conditions in the mine; development of control engineering for the automatic access to the mine.

References

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