DESIGNING A SYSTEM THAT REMOVES METALLIC INCLUSIONS FROM BULK RAW MATERIALS ON THE BELT CONVEYOR

Modern industrial technologies require raw materials of high purity from suppliers, especially due to the possible presence of inclusions of heterogeneous metals in them. The existence of metallic inclusions of heterogeneous metals in the raw materials leads to equipment failure, a decrease in the quality of output products, and, consequently, large financial losses. Since the main method of transporting raw materials in the industry is still a conveyor belt, this imposes additional conditions to control and remove metallic inclusions. For various reasons, current methods for removing metallic inclusions in the conveyor belt do not fully meet the needs of modern production. The main issue related to existing removal systems is the lack of intelligent interaction between these systems and the absence of information exchange between systems that detect and remove metallic inclusions. An alternative method for removing metallic inclusions of heterogeneous metals from loose medium has been proposed, which implies the tandem operation of the system that detects metallic inclusions and the system that removes them. The tandem operation of the two systems makes it possible to exchange information about a detected metallic inclusion and, as a result, to more flexibly use tools for the removal of metallic inclusion depending on the size and location of the metallic inclusion relative to the conveyor belt axis. At the same time, the control unit of the removal system makes it possible to control the conveyor belt itself, which allows the removal of complex metallic inclusions using the reverse of the electric drive of the belt, as well as enables a control check of the fact of removal. The developed algorithm of the removal system was implemented in the programming environment TIA-Portal. The introduction of this removal system could reduce the number of metallic inclusions in raw materials by 15–20 %; moreover, its application is not limited to only one sector of the national economy

Keywords: metallic inclusion, conveyor belt, detection system, removal system, magnetic separator, electromagnet

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1. Introduction

Any modern production requires the supply of high-quality raw materials, which implies not only high chemical and physical indicators but also the absence of inclusions in raw materials, and especially metallic inclusions. They are very dangerous for both manufacturing equipment and the quality of output articles. The issue related to the presence of metallic inclusions is apparent from the moment the raw materials are delivered to a plant; inclusions may penetrate them at various stages of processing, packaging, and transportation. In addition, at an enterprise, the accidental penetration of part of the metal into the raw materials is not at all rare [1]. Such processes occur both during the manufacturing operations (mills, crushers, mixers, presses) and due to the inattention of service personnel. The presence of metallic inclusions in raw materials leads to the failure of manufacturing equipment, a decrease in productivity at the enterprise, a decrease in the quality of finished products, as well as financial costs for the elimination of emergencies and the downtime of manufacturing lines. In addition, the task of removing metallic inclusions is often considered as an issue

related to the enrichment of iron-containing ores [2], which is no less relevant. Devising the methods for controlling (detecting) metallic inclusions in raw materials should also imply the possibility of their removal, which, in turn, requires that appropriate technical means should be designed. Given this, the subject matter of this work aimed at devising a system for removing metallic inclusions in bulk raw materials in the belt conveyor, based on the advanced hardware and software tools is relevant. Solving this task would improve both the reliability of manufacturing equipment and the quality of raw materials.

2. Literature review and problem statement

When analyzing the current status of development of systems that remove metallic inclusions, it should be noted that the issue of removing metallic inclusions from raw materials is relevant not only for a particular industry but is a general problem. It is pressing for the construction industry, agriculture, food industry, as well as in mining and recycling. The easiest method of removing metallic inclusions is

the solution given in work [3]. The use of a drum separator simplifies the design but does not resolve the issue of metallic inclusions in the significant weight category. Paper [4] describes the process of upgrading a classic drum separator by changing the mode of operation of the feeder, as well as the design of the separating tank and its location; these solutions, however, improved the efficiency of detecting metallic inclusions only partially. An option to overcome these difficulties is to use different types of magnetic materials for permanent magnets [5]. However, this solution only slightly increases the proportion of metallic inclusions removed. Despite the rather mediocre efficiency, these techniques are often used on industrial lines [6]. However, this approach does not make it possible to automatically unload the electromagnets from removed metallic inclusions. Quite promising is the technique given in work [7], which involves the combined effect on metallic inclusions exerted by the magnetic field and airflow. The problematic point of this approach is the difficulty in determining the force of airflow due to the lack of information about the size of metallic inclusion. More innovative is the technique to use magnetic balls described in work [8]. However, given the low level of research and the specificity of application, its scope is rather narrow due to the different and heterogeneous physical and mechanical characteristics of different types of raw materials. Worth noting are the self-unloading separators by Goudsmit Magnetic Systems [9]; however, they do not allow the removal of metals with considerable weight and complex geometry. The use of hybrid electromagnetic separation systems, described in work [10]. significantly improves the efficiency of such systems by generating a magnetic field induced in the predefined area of space. However, the lack of information about the detected metallic inclusion makes such a system "blind" and ineffective. The issue of automation of removal systems is the most unexplored one. In work [11], the automation is reduced to managing the main mechanical and kinematic parameters of the separator; no control over a magnetic flow and its characteristics was considered.

In summary, it can be specified that most existing systems that remove metallic inclusions possess a low level of automation regarding the process of removing and unloading removed metal. The low current level of the intelligent saturation of these systems does not allow this process to be carried out with high energy efficiency. Given that existing removal systems in most cases operate separately from the metallic inclusion detection system, their joint work is impossible. That does not make it possible to expand the functionality of the system. It should also be noted that most removal systems are not versatile but intended for narrow sectoral applications.

3. The aim and objectives of the study

The purpose of this study is to devise an alternative system for removing metallic inclusions from bulk raw materials in the conveyor belt. The system to be developed should provide the possibility of removing metallic inclusions of heterogeneous metals, metal inclusions of complex configuration and different weights. In addition, the system must provide

for the possibility of joint operation of two systems. That would make it possible to optimize the mode of operation of working bodies of the system of removal and automatic unloading of deleted metallic inclusions.

To accomplish the aim, the following tasks have been set:
– to develop a structural scheme of the system for removing metallic inclusions with its binding to the system of their detection, which would make it possible to exchange data between them. In particular, transmit data on detected metallic inclusions in raw materials;
– to develop a hardware and communication complex based on the advanced hardware and software tools to ensure maximum functionality of the system that removes metallic inclusions;
– to develop software and algorithmic support for the removal system in order to implement optimal operation of metal inclusion removal bodies and ensure the autonomy of the system operation.

4. The study materials and methods

To address the task set and acquire statistical data, a local building materials plant was chosen, VAT Keramikbudservice (Ukraine). Like for other factories in the industry, the main issue related to the quality of raw materials is the metallic inclusions that penetrate them, which cause frequent breakdowns. After analyzing the scheme of the manufacturing line (Fig. 1) that supplies raw materials, specifically crushed clay, we realized that the only available tool to remove a metallic inclusion is an electromagnet unit. In this case, such a technique, according to our analysis, removes only 65 % of the available metallic conclusions. This indicator by no means allows for an uninterrupted operation of manufacturing lines of the plant in general.
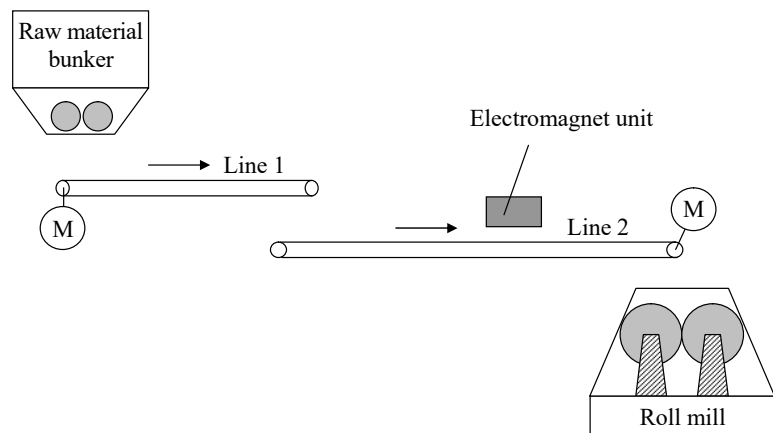

Fig. 1. Technological scheme of raw materials supply

The conveyor scheme includes two conveyor lines with independent electric drives. In this case, the raw material supply bunker, which is an auger mixer of raw materials, located above line 1, is synchronized with the electric drive of line No. 1. Raw materials from line No. 1 arrive to the conveyor line No. 2, from where it enters the roll mill.

In order to provide the removal system with the necessary information about the parameters of a detected metallic inclusion, it was decided to use the preliminary results from devising a method for detecting metallic inclusions based on

a scanning signal [12]. The method essentially implies the formation of a scanning signal with a moving maximum amplitude of the intensity of the magnetic field of the "bell-shaped" form within the width of the conveyor belt. This approach makes it possible to identify the presence, localization relative to the cross-section of the conveyor belt, the overall dimensions of metallic inclusions.

5. Results of devising a system that removes metallic inclusions

5. 1. Development of the structural scheme of the system

Earlier experience in modernization [13] has testified that the use of a system for detection of metallic inclusions only and a conveyor belt reverse control as a method of removing metallic inclusions does not yield the expected result. That causes a significant overconsumption of raw materials as an accompanying product of the removal. Therefore, building a tandem full-fledged removal system is the main task. As a result, the technological scheme was supplemented with appropriate elements and units, Fig. 2.

Based on the technological scheme of the line, the function and capabilities of the method of detection and removal of metallic inclusions, as well as the requirements by target enterprises, an innovative system for removing metallic inclusions has been proposed; its functional scheme is shown in Fig. 3. It includes the detection system and removal system, as well as a general factory conveyor belt control system.

The connection between the detection and removal systems is enabled by ModBus RTU protocol [14]. In addition, Ethernet communication with the general factory conveyor belt control system is implied for stopping, reversing, or slowing down the conveyor belt movement. The reverse of the conveyor belt makes it possible to re-control the presence of a metallic inclusion in the raw material after its removal. In addition, the reverse mechanism makes it possible to remove those metallic inclusions that were detected after repeated control of their presence. This was made possible by placing receiving container No. 1 for undetected metallic inclusions under the belt. This process, although it is expensive in terms of the loss of raw materials and manufacturing time, is non-alternative when removing large and metallic inclusions that are an inseparable part of the raw materials. In addition, the reverse mechanism allows the removal of metallic inclusions of non-ferrous metal to container No. 1, which are detected by the detection system but cannot be removed by the removal system as they are not magnetic. The slowdown mode makes it possible to re-control metallic inclusions in the raw material, which improves the level of detection.

The removal system (Fig. 4) consists of the following nodes that perform the functions assigned to it. The command to stop the preceding line is given at the time of stopping the current line or its reverse in order to avoid the accumulation of raw materials on the current line.
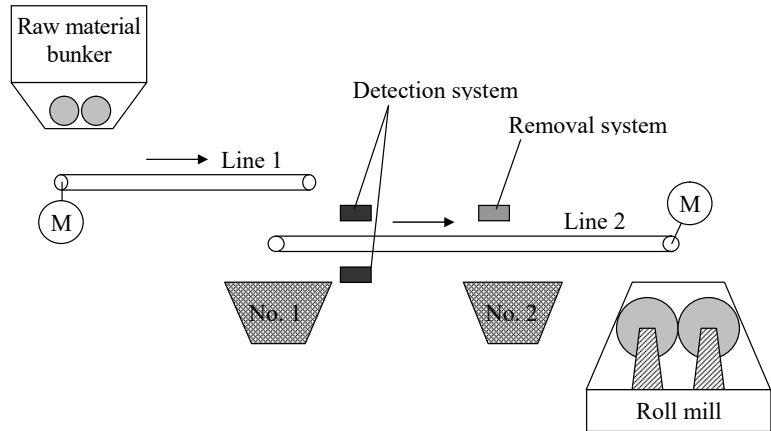

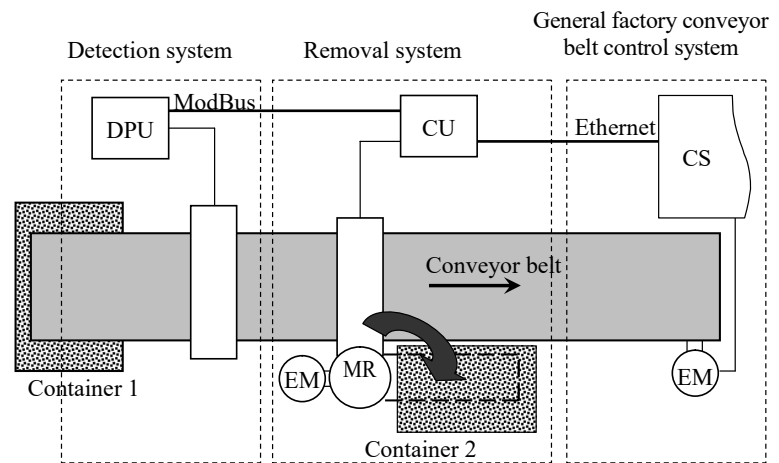Fig. 2. Technological scheme with complementary detection and removal systems

Fig. 3. Functional diagram of the system: DPU — data processing unit; CU — control unit; CS — control system; EM — electric motor; MR — mechanism of rotation

The electromagnet unit (EMU) contains 4 independent electromagnets (EM1–EM4). The number of coils was determined based on the geometric dimensions of the electromagnets, conveyor belt, and a minimal magnetic flux of the electromagnet. The independence of these electromagnets implies the possibility to selectively enable one or more electromagnets depending on the location of a metallic inclusion and its dimensions. In addition, this approach makes it possible to briefly turn on the electromagnets at power, which is allowed by the manufacturer as short-term but prohibited as permanent. This function would remove heavy and large metallic inclusions, as well as those that are covered with a large layer of raw materials or an inseparable part of the raw materials. Switching to the holding capacity makes it possible to keep the metal removed from the raw materials on the electromagnet core at minimal electricity consumption.

The rotation mechanism (RM) executes a radial rotation of the electromagnet unit between the metallic inclusion removal points and the point of discharge of the metallic inclusions to receiving container No. 2. The electric drive of the rotation mechanism is a reverse electric motor (EM), connected to it using a worm gearbox. It is the use of this type of gearbox that makes it possible to fix the rotation mechanism at working points. Positioning sensors (PS) are used to control the

position at extreme points; they are triggered at the removal point and discharge point of metallic inclusions. Information from the positioning sensors enters the control unit (CU). This unit receives information from the metallic inclusion detecting system about the presence, size, and location of a metallic inclusion on the conveyor belt. As a result, the control unit decides to enable the required number of electromagnets, taking into consideration the time delay in the movement of a metallic inclusion from the detection point to the point of removal of metallic inclusion. In addition, the control unit determines which of the electromagnets is to be turned on to remove metallic inclusions in order to effectively and economically manage the removal process. If necessary, the system involves a reverse conveyor belt mechanism to confirm the fact of removing metallic inclusions from raw materials.
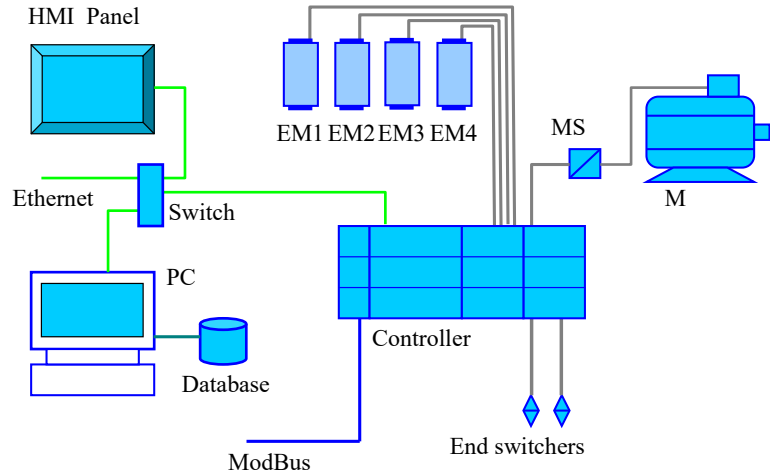
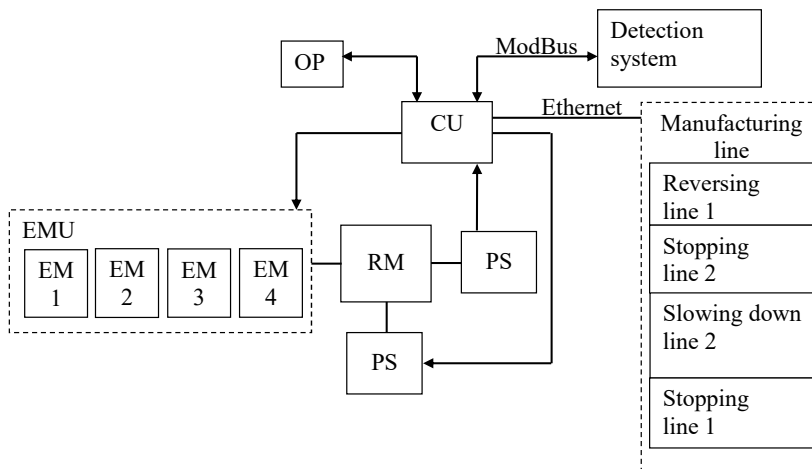Fig. 5. Removal system functional diagram

Fig. 4. Structural diagram of the removal system: EM1-EM4 — electromagnet; EMU — electromagnet unit; RM — rotation mechanism; EM — electric motor; CU — control unit; PS — positioning sensor

Taking the structural scheme as the basic variant, we devised a functional diagram (Fig. 5). The diagram shows communication channels and the main functional units and assemblies.

An advanced functional solution is the process of discharging a removed metallic inclusion to container No. 2. To this end, the control unit turns on the electric motor, which serves as an electric drive of the rotation mechanism of the electromagnet unit. The mechanism turns at 90°. The endpoint sensor is triggered and the control unit stops the electric motor. The next step is to turn off the electromagnets; metallic inclusions enter container No. 2 for the removed metal. After that, the control unit returns the electromagnets unit to the removal point, and the positioning sensor controls this movement.

5. 2. Implementing the hardware and communication complex

The control unit is a controller made by Siemens (Germany) (Fig. 3), series S7-1200, model CPU 1214 (Germany) [15]. This controller has 16 input ports and 16 discrete signal output ports. In addition, it has 2 analog inputs in the range of 0–10 V. To expand the functionality of the system, there is an extension using the SM1221 module (Germany) and the SM1222 module. These modules provide an additional number of I/O ports. In order to enable the exchange of data between the systems that detect and remove metallic inclusions, the data transfer protocol ModBus RTU (Modicon, France) is employed. To this end, the controller is equipped with a communication processor CP1241 (Germany), which supports the physical level of the ModBus RTU protocol – RS-485 (Fig. 6).
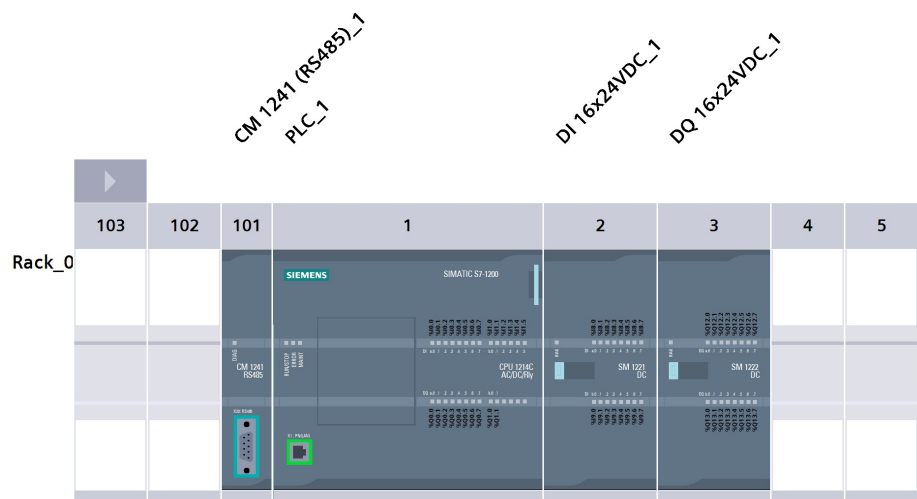
Fig. 6. Arrangement of the main controller's rack

To execute operational control and site-specific control, the system includes an operator panel (OP), which displays the current information about the process of detecting and removing metallic inclusions; there are also buttons to control this process. To this end, the touch panel KTP700 by Siemens (Germany), measuring 7 inches diagonally, was chosen (Fig. 7).
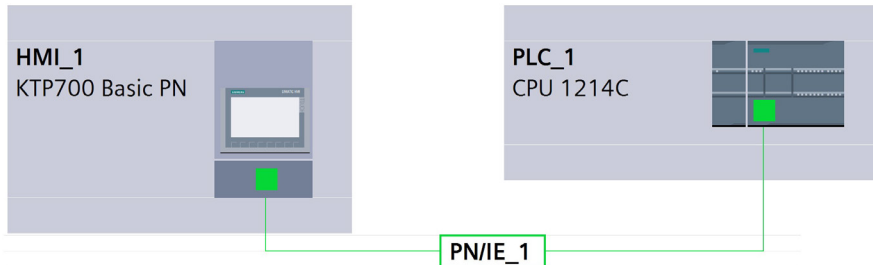
To implement the ModBus protocol, a map of registers was devised, to which the removal system applies. The registers store data on the presence and longitudinal geometric dimensions of a metallic inclusion, the metal type, detection time Table 1.

All registers of the detection device use the unsigned integer 16 bit data format. Employing the same type of data makes it possible to unify the functions of reading and writing data in registers. The main ones for the removal system in the registers of the detection system are the registers that are responsible for the type of metal found on the conveyor line, and its intensity relative to the longitudinal coordinates of the same conveyor line. An example of encoding an existing metal in the device registers is shown in Fig. 8.

Fig. 7. Communication connection between the controller and operator panel

Table 1

List of available registers for the system that detects metallic inclusions

Operation code	Register address	Data format	Parameter name	Range of acceptable values	Values by default
03	0	uint_16	device identifier	0–9999	0x4073
03	1	uint_16	device number in the network	0–254	0x01
03/06	2	uint_16	data exchange speed	1–1200 baud 2–2400 baud 3–4800 baud 4–9600 baud 5–19200 baud 6–38400 baud 7–57600 baud 8–76800 baud 9–115200 baud	0x07
03/06	3	uint_16	data bit size	0–7 bits 1–8 bits	1
03/06	4	uint_16	parity type	0–disabled 1 – even 2 – odd	0
03/06	5	uint_16	number of stop nits	0–1 stop bit 1–2 stop bit	0
03	10	uint_16	fact and type of detected metal	0 – lacking 1 – ferrous 2 – non-ferrous	0
03	11	uint_16	metallic inclusion presence index at point X_1	0–65535	0
03	12	uint_16	metallic inclusion presence index at point X_2	0–65535	0
03	13	uint_16	metallic inclusion presence index at point X_3	0–65535	0
03	14	uint_16	metallic inclusion presence index at point X_4	0–65535	0
03	15	uint_16	metallic inclusion presence index at point X_5	0–65535	0
03	16	uint_16	metallic inclusion presence index at point X_6	0–65535	0
03	17	uint_16	metallic inclusion presence index at point X_7	0–65535	0
03	18	uint_16	metallic inclusion presence index at point X_8	0–65535	0
03	19	uint_16	metallic inclusion detection time – hour	0–23	0
03	20	uint_16	metallic inclusion detection time – minute	0–59	0
03	21	uint_16	metallic inclusion detection time – second	0–59	0
03/06	22	uint_16	metallic inclusion presence detection threshold	1–60000	100

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	T
t_1	0	80	0	0	0	0	0	0	0
t_2	20	290	110	30	5	0	0	0	1
t_3	0	10	80	1200	80	0	0	0	1
t_4	0	0	0	10	1200	290	10	0	1
t_5	0	0	0	0	0	10	8	0	0
t_6	0	0	0	0	0	0	0	0	0
t_7	0	0	5	5	5	0	0	0	0
t_8	0	5	1150	1230	1150	5	0	0	1
t_9	0	0	5	5	5	0	0	0	0
Zones for indexed registers	11	12	13	14	15	16	17	18	19
	Data register address								

Fig. 8. Example of register contents

the metallic inclusion removal system. There is also a window for configuring systems and operations. In Fig. 9 shows a working window of the metallic inclusion detection system. It depicts a conveyor belt, as well as inductive detection coils. The sensitivity threshold for configuring system settings is also set. In the working window, there is a possibility to access the detection archive window, as well as the working window of the system for removing metallic inclusions.

If a metallic inclusion is detected, the working window of the system appropriately visualizes the process. The diameter of the red circle, symbolizing a metallic inclusion, indicates the conditional size of the metallic inclusion, and its position relative to the cross-section of the conveyor belt corresponds to the real position on the belt Fig. 10.
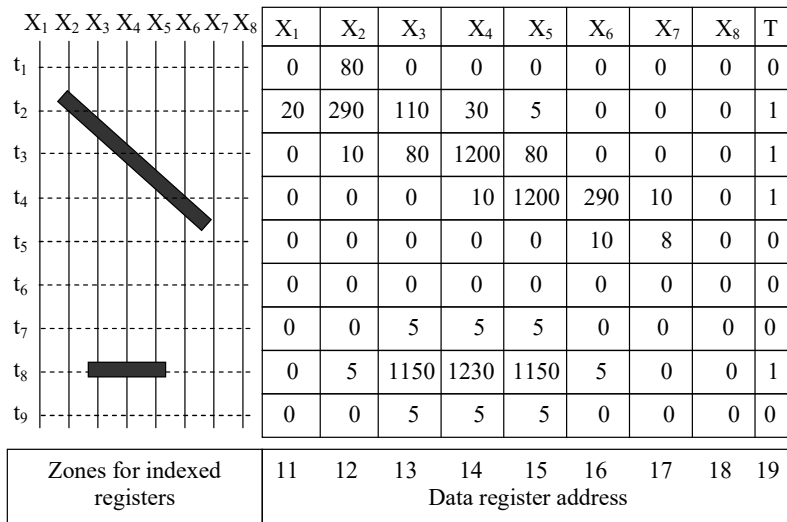
Depending on the location of a metallic inclusion, the conveyor belt is divided across into 8 zones, which are correlated with the registers of the detection system data. When a metallic inclusion enters the transverse zone of the detection system coils, the system scans this cross-section while forming eight values corresponding to the indexes, and enters the measured values in the corresponding registers (addresses 11–18). The value of the index depends on the size of the metallic inclusion, which causes a change in the intensity of the measured signal by the detection system. The register responsible for the fact and type of the detected metallic inclusion (address 10) is filled with the corresponding value depending on the type of the detected metallic inclusion. Thus, if the metallic inclusion is detected, the number "1" is entered; when detecting a non-ferrous metallic inclusion, the number "2" is entered. The fact of detection is established if at least in one of the zones revealed a metallic inclusion with an index exceeding the detection threshold. This detection threshold is stored in the detection system data register (address 22). The register value can be changed from the operator panel to adjust the sensitivity threshold of the system that removes metallic inclusions. In addition to the registers of metallic inclusions, there are time fixation registers t_i for each scan point (addresses 19–21) that are updated each time the registers of the presence of metallic inclusions are updated. This information greatly facilitates the removal system to calculate the moment of enabling electromagnets to remove the detected metallic inclusion.

5. 3. Developing the software and algorithmic support

In order to enable operational control, a SCADA system was developed in the environment TIA-Portal v15 [16] for the operator panel KTP700 [17]. It has two main windows, which are responsible for the metallic inclusion detection system and
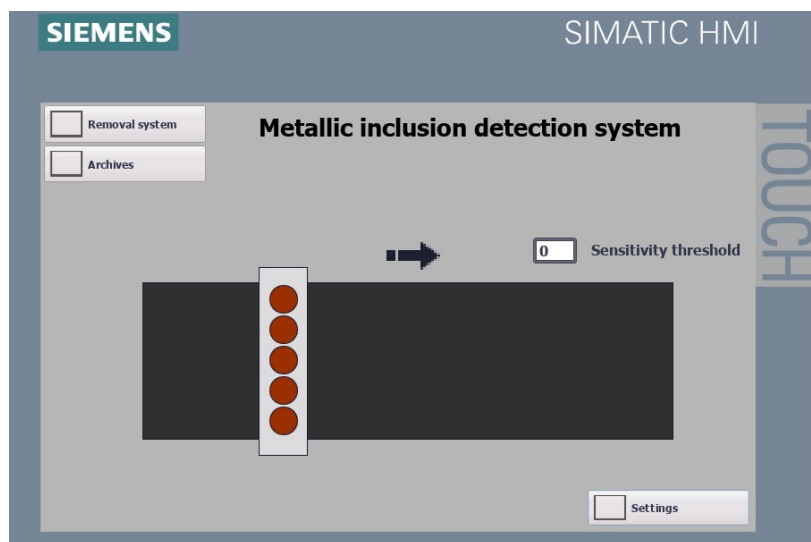

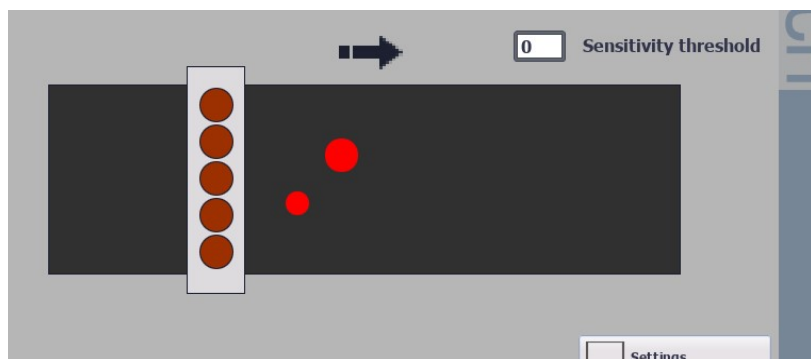Fig. 9. Working window of metal inclusion detection system

Fig. 10. Working window showing the detection of metal inclusions

Fig. 11 shows the working window of the metallic inclusion removal system. It similarly depicts the conveyor belt and the removal mechanism with electromagnets and containers for receiving metallic inclusions in two ways – removal through the reverse mechanism of the conveyor belt, as well as with the help of electromagnets. For the case of electromagnet removal, the electromagnets involved in the removal are displayed in red,

which makes it possible to monitor the process in animation. For the case of removal through the belt reverse mechanism, the corresponding animation of the conveyor belt drive is displayed.

All detected and removed metals are registered in the SCADA system archive.

In order to enable the functioning of the system of removal of metallic inclusions and its main components, an algorithmic flowchart of the system as a whole was developed (Fig. 12). The first step is to read data from the ModBus registers of the detection system, in which all current information about detected metals and their parameters is stored. In case there is confirmation of metal detection, the program proceeds to check the set sensitivity threshold. This threshold, as described above, is set so that a removal system responds to the metallic inclusions that pose a threat to manufacturing equipment.

In the absence of a metallic inclusion or its insignificant weight, the algorithm returns to its start.

The next step in the algorithm is to determine what type of metal is present in the detected sample – "ferrous or non-ferrous". In the case of a "non-ferrous" metal, the system is not able to remove metal using electromagnets, and, therefore, another removal technique is implemented. According to the algorithm, it is to stop conveyor belt No. 1 and the next reverse of the No. 2 belt. As a result, raw materials containing a "non-ferrous" metallic inclusion enter the refused container. After the time delay, the conveyor line is restarted – the belt No. 2 is switched on in the normal direction, followed by belt No. 1. The algorithm returns to its start again.

In the case of detection of a "ferrous" metal, the algorithm works to control electromagnets. As a result, electric magnets are powered at full capacity to remove metal from raw materials. In this case, those electromagnets that are placed in the path of metallic inclusion and correspond to its dimensions are turned on, thereby saving electricity. After the time delay, the power of electromagnets is transferred to the "hold" mode. In the case of setting up the system for re-scanning the presence of metallic inclusions, the algorithm returns to the moment of reverse of the conveyor belt for re-scanning. In the absence of the need for re-scanning, the algorithm checks the size of current metallic inclusion using the information from the registers. In the case of a small weight of the metallic inclusion, the algorithm returns to its start. That is, the removed metallic inclusion is held on the electromagnet as accumulated one. If the current metallic inclusion mass is large, or there are already several small metallic inclusions on the electromagnet, the system, according to the algorithm, unloads the electromagnet unit. The drive of rotation of the electromagnet unit is turned on, until the sensor of the end turning point is triggered. The next step turns off the power of electromagnets, to discharge the metallic inclusions to the refused container. Subsequently, according to the algorithm, the electromagnet unit returns to the initial "removal" position until the final position sensor is triggered. Again, the algorithm returns to its start, which makes the algorithm cyclical.
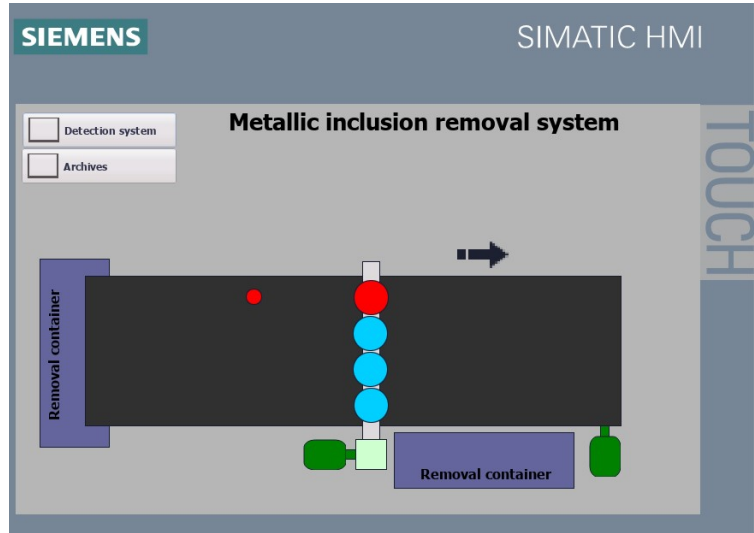

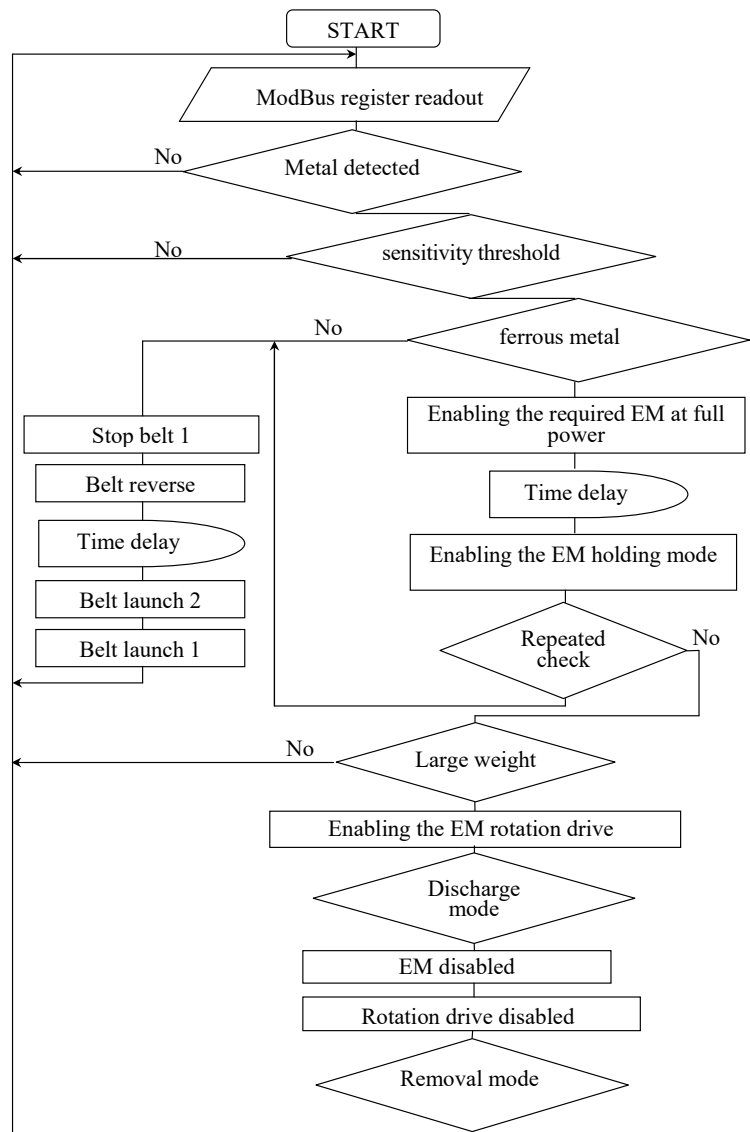Fig. 11. Working window of metal inclusion removal system

Fig. 12. Flowchart of the algorithm for removing metallic inclusions

6. Discussion of results of devising a system of removing metallic inclusions

The structural scheme of the system of removal of metallic inclusions from bulk raw materials in the conveyor belt (Fig. 4) has been constructed, which, in comparison with similar systems [4, 5], allows its joint work with the system of detection of metallic inclusions. It enables the exchange of data on the detected metals in raw materials. The absence of such data exchange in the systems discussed above causes them to work blindly, which does not make it possible to control the process of removing metallic inclusions and confirming it. The feature of system operation under a tandem mode significantly expands its capabilities.

The functional scheme of the removal system developed on the basis of the structural scheme (Fig. 5) implied the selection of its functional components, which enable independent unloading of removed metallic inclusions and bringing the system to a working state. In contrast to [9], where unloading is carried out by a conveyor technique, our system makes it possible to remove metallic inclusions of a larger weight category and complex configuration by using four independent electromagnets. In this case, each electromagnet can work under different modes of power. This approach to the choice of power and the choice of the electromagnet number makes it possible to provide for an optimal and more economical mode of its operation.

The developed hardware and communication complex has made it possible to fully implement the functional scheme of the system (Fig. 6). In particular, the use of the communication processor CP1241 allowed communication to exchange data between the detection and removal systems. And the development of the ModBus-registers map (Table 1) has made it possible to implement their communication environment of data exchange. Thus, an example of the contents of registers (Fig. 8) demonstrates the typical exchange of data. In addition, organized Ethernet communication (Fig. 5, 7) with the general plant control system, provides for a possibility to implement direct control of conveyor belts to remove detected non-ferrous metals. This solution has made it possible to significantly increase the functionality of the system in general. In contrast to [10], where the problem of communication with the detection system is not solved and, as a result, the system does not have information about the place of formation of the magnetic field, our system is deprived of this disadvantage.

The developed software and algorithmic support of the system has allowed us to implement its functioning under an automatic mode. In particular, the developed algorithm (Fig. 12) has made it possible to implement the function of data exchange and removal of metallic inclusions and their subsequent unloading. At the same time, there is a mode for removing non-ferrous metals by managing the conveyor belt. In contrast to [11], the task of automation of the removal process is solved more comprehensively and functionally. Thus, our removal system has a mode of control over the removal of metallic inclusions, which implies re-monitoring their presence. In addition, the use of the KTP700 operator panel (Fig. 9–11) has made it possible to execute operational control and system management, which significantly expanded the functionality and informativeness of the metallic inclusion removal system.

Given the peculiarities of the physical properties of raw materials (clay), which imply their insufficient looseness and high humidity, the task of removing non-ferrous metals has not been solved completely. In our system, the removal of metallic inclusions of non-ferrous metals is carried out through the reverse mechanism of the conveyor belt, and this, in turn, leads to the overconsumption of raw materials. Although non-ferrous metallic inclusions make up a small part of all metallic inclusions, this issue requires further research and technical solutions.

7. Conclusions

1. A structural scheme of the metallic inclusion removal system has been developed, which combined two systems (detection and removal of metallic inclusions), which has allowed us to ensure their joint work, organize data exchange, and expand the functionality of the system. The functional scheme, developed on its basis, ensures the implementation of the assigned tasks for the detection, removal, and unloading of detected metallic inclusions and makes it possible to separately control the electromagnets and select their power and time points.

2. The hardware and communication complex, developed on the basis of the advanced hardware and software tools, has allowed us to solve the tasks set for the metallic inclusion system; the use of ModBus communication and the CP1241 module has made it possible to organize data exchange between it and the metallic inclusion detection system.

3. We have developed the software and algorithmic support of the system, the use of which makes it possible to reduce the number of metallic inclusions in raw materials by 15–20 % compared to existing removal systems. The implementation of algorithmic support allows the system to remove large-scale and non-ferrous metallic inclusions. The use of the software makes it possible to execute separate control of electromagnets, which significantly improves the efficiency of the system.

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