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DIAGNOSIS OF PROCESS EQUIPMENT IN THE PROCESSING OF CABLE WASTE, BASED ON ARTIFICIAL NEURAL NETWORKS

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Abstract: *The article discusses the increasing efficiency of the technological equipment for the processing of cable waste. It is proposed to solve the problem by using modern expert systems, such as artificial neural networks (ANN), which will allow diagnosing the working system of the equipment, making technical and technological assessment of its condition effectively, taking into account noisiness of input data. The solution to the technological problem is based on the use of artificial intelligence methods, based on artificial neural networks, which allow achieving new functionality of the cable waste processing line and improving the quality of technical diagnostics.*

Keywords: *Cable waste processing technology, artificial neural network, cable scrap, ground flakes, copper shavings, aluminum shavings, mathematical modeling, automated diagnostic system, neuroinformatics, hybrid control system, standard artificial neuron, Rozenblatt perceptron, multi-layered neural network.*

Effectiveness of cable waste recycling technology is reduced to simultaneous harmonizing the performance, self-cost and cost of end products. This is quite a difficult task, as it is necessary to develop a technology that fully meets the real production objectives.

Modern process equipment is focused on diagnosing technology systems, using mathematical modeling method [1, 2]. However, this method does not provide enough ability to track and accordingly control many technological factors at the same time, which have a negative impact on the entire technology. Solution to this problem can be achieved with the use of modern expert systems, such as artificial neural networks (ANN), which will allow diagnosing of the working system, making technical and technological assessment of the condition, taking into account noisiness of input data [3, 4].

The composition of cable waste is very complex in terms of components, which is determined by processibility (recyclability), built based on the quality of produced end product and cost of processing cable scrap. In addition, there is no unified methodological support for this production process, and each cable company develops its own approach to choosing the level of processibility of the processing process.

Waste of cabling and wiring products contains valuable raw materials, which, with a well-chosen separation method, will allow obtaining secondary raw materials of the sufficiently high quality (copper and aluminum purity is up to 90%). Composition of cable products includes various materials (Fig. 1), but the main one is the metal conductive part (50-60%) and polymer insulation (15-25%). Choice of the recycling method will ensure proper output percentage of purified secondary raw materials, which will make it possible to return almost 90-95% of cable waste into the production cycle.

a) *b)*

Fig. 1. ***Received recyclables:*** *a) Copper shavings; b) Plastic compound*.

Today, there is a problem of reuse of various polymeric materials from which the cable insulation is made, because there is heterogeneity in its composition, namely the combination of layers of different types of polymers and their subsequent mixing, which significantly worsens the properties of the output material.

With regard to the processing of metal cable cores, this problem is not so acute, since the live part is usually made of pure electrical copper or aluminum. However, in order to improve the mechanical characteristics of cable products, armor is often used, which is made of steel elements (wire or tape). Being a structural element, and therefore, its component part, the armor is also subjected to crushing and, accordingly, this stage significantly worsens the properties of aluminum and copper shavings, due to ingress of foreign metals during crushing.

Based on the foregoing, one of the main issues, facing the high-quality technology of cable production waste processing is the issue of increasing the percentage of separation of non-ferrous metal from insulation and other accompanying metals, included in the design of the cable product. Recycling of waste of insulation, armor and polymer coatings (shells) is also an important issue, since the resulting polymer mass and metal shavings (non-metallic components) will allow solving various production and economic problems, with the obligatory observance of the high percentage of purity during cable processing.

The technology of processing cable waste combines several methods: electromagnetic separation, air vibro -separation, etc., during which polymer and metal components of the cable product are separated from each other.

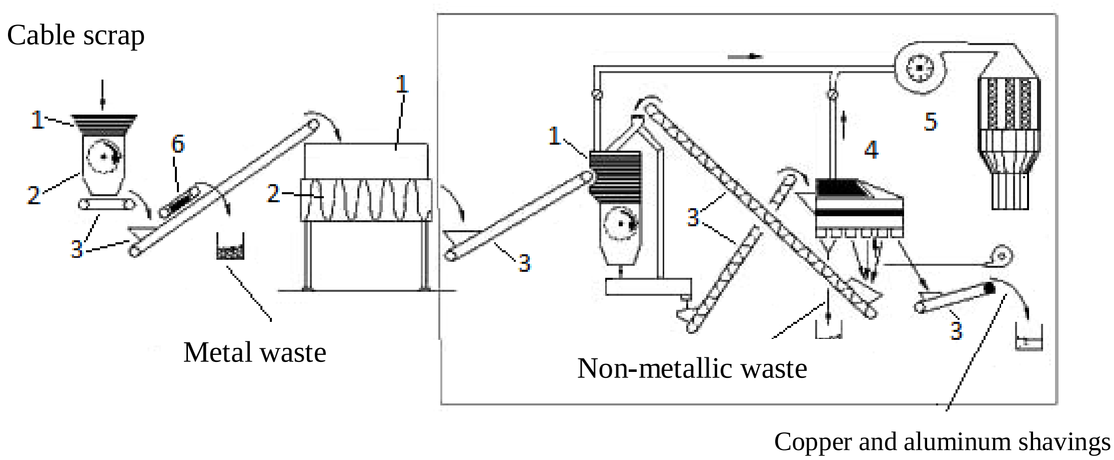

Fig. 2. ***Technology line scheme for recycling cable waste:***
1-charging hopper; 2 – crusher; 3 – conveyor; 4 –vibrating screen; 5 – air vibroseparation system; 6 –electromagnetic trap (catcher).

A feature of this technology is the crushing of waste in closed cycle (Fig. 2), where in the process of crushing the metal conductor is separated from the insulation, which is achieved by different density of materials, being recycled. At the same time, this technology should not be used when processing sticky, oil-filled cables).

For provision of uninterrupted and efficient operation of process equipment, more than 85 technological parameters shall be monitored. Therefore, sophisticated modern equipment and growing level of technical requirements for both technology and finished product require a revision of the current traditional concept, associated with the construction of diagnostic system and search for solutions [7].

The most vulnerable place in the technology in question is air vibro-separation in a pseudo-boiling layer [5, 6]. Proposed method will allow carrying out control of the operation mode of waste recycling line by tracking parameters of equipment operation mode and matching them with technology-set values.

At the same time, the equipment is considered as an electromechanical system that includes working nodes and mechanisms (figure. 2): crushers, conveyors, an electromagnetic trap, vibrating screen and air vibration separation system, as well as an automated diagnostic system (ADS), adjusting the entire line operation as a whole, taking into account the change of the cable scrap (copper or aluminum). Diagnosis of the entire process cycle will allow assessing of EMC current state, identifying the need for changing the vibrating screen - to determine the degree of its clogging, while reducing the maintenance time by predicting the “point of complete failure”. At the same time, each element has its own set of major faults and zones of limitations, timely detection of which will ensure an increase in the reliability of the entire technological line.

Technological equipment includes automated diagnostic system (ADS), which operates on the basis of an expert system, which is a new information technology in the recognition of signals of both EMC working parameters and cable scrap (raw materials). Line operation as a hybrid system can be considered as the joint operation of EMC monitoring and diagnostic devices, as well as integrated intelligent computer technology. The use of neural networks for diagnosis will allow timely assessment of the technical condition of work nodes and mechanisms, as well as the degree of knife wear in crushers, clogging of vibro-installation screens and air vibrating system filters. At the same time, artificial neural networks (ANN) are computational structures that consist of a large number of homogeneous elements, each of which performs relatively simple functions. A distinctive feature of the proposed method is the fact that ADS has the ability to training, i.e. the neural network is able to accept and recognize information, communicated to it, or what they attempt to obtain from it, to select the required operating mode (in our case, the transition from aluminum raw materials to copper or vice versa), to signal the need to replace technological equipment (knives, screens, filters) and to start the mode of cleaning equipment when switching to new raw materials).

Solution to the technological problem is based on the use of artificial intelligence method, based on artificial neural networks, which will allow achieving new functionality of the cable waste processing line and improving the quality of technical diagnostics. The main role in the technology under consideration is given to the system of controllers and sensors (vibration sensor, noise sensor and weight sensor), which will capture and control values: working parameters of crushers, magnetic trap, belt conveyors, vibrating screen of air vibro-separation system (fig. 2). Correct choice of ADS elements will allow covering the most extensive area of indirect data of the operating system, including raw materials parameters (cable scrap), ground flakes (cable grind), metal and non-metallic waste, copper and aluminum shavings, and will also make it possible to read data most accurately and eliminate the influence of third-party factors that create interference and noise. All this will enhance the capabilities of process equipment by identifying ANN factors-the most important factors for the working line by creating of common image of controlled technology system. At that, parameters of the system (Figure. 3) – are data (p), read by sensors, and ADS itself has no impact on the current control system (CS) of the process equipment, since the control process (x) begins from the moment when the installation is set to training (data collection from sensors and their storage) with the subsequent addition of control signals to the operation of ADS line EMC, which will ensure improvement of the equipment operation. Output signal (y) – this is a parameter of system state of the analytical part operation. More accurate analysis of changes regularity in the technological parameters of the system can be achieved with the number of measurements equal to 10,000. Software support - ANN and standard controller drivers.

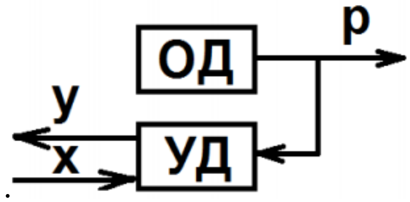

Fig. 3. ***ADS block scheme of process equipment for processing cable waste.***

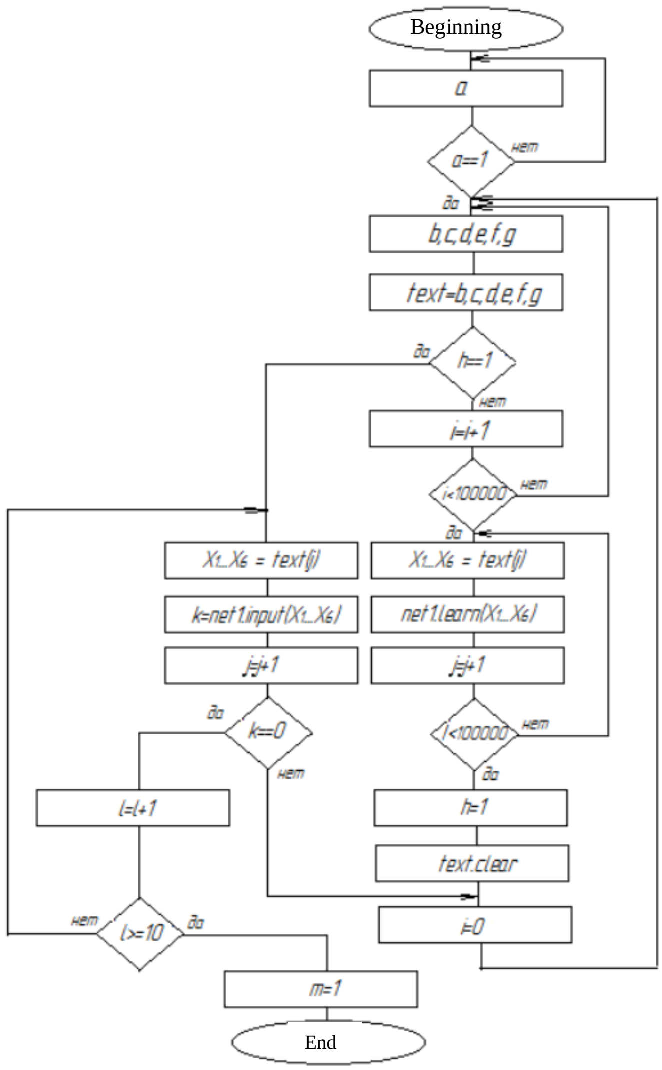

Fig. 4. ***Block scheme – algorithm of ADS operation.***

In the given block scheme (Figure 4), which represents algorithm of ACS operation, there are the following designations: a – object status parameter; b, c, d, e, f – control sensors values; g – scrap, grind and shavings parameters, i, j – meters; X_1-X_6 – text file line with a-g parameters, respectively; h – training option (whether it was or not); k – neural network result; l – fault; m – state of the system (0 – everything is O.K, 1 – there are problems); text – text variable to record parameters. Thus, ANN has the ability to change its behaviour depending on external conditions. Ability to recognize the presented input signals and ability to training allows developing of the required reaction for the hybrid control system to continue the required process cycle, established by the regulatory documentation. Completion of the training procedure will allow NS to cut off external third-party signals, ensuring purity of the operating background for the equipment.

A distinctive feature of the ANN, as a hybrid ACS for the cable waste processing line is its ability to fault tolerance, which is that in the event of a neuron failure, as well as in the case of the network connection distortion, this practically does not affect the operation of the entire installation as a whole, while the joint behavior of the network and technological equipment ACS changes slightly. If the behavior changes, the system continues operating, it does not die, because information is distributed throughout the network, rather than contained in a specific location.

Thus, the possibility of using ANN in technology control as a hybrid system, combined with technological line ACS has become possible thanks to neuroinformatics, with the help of which it is possible to develop and study various production tasks by means of artificial neural networks, built on standard artificial neurons.

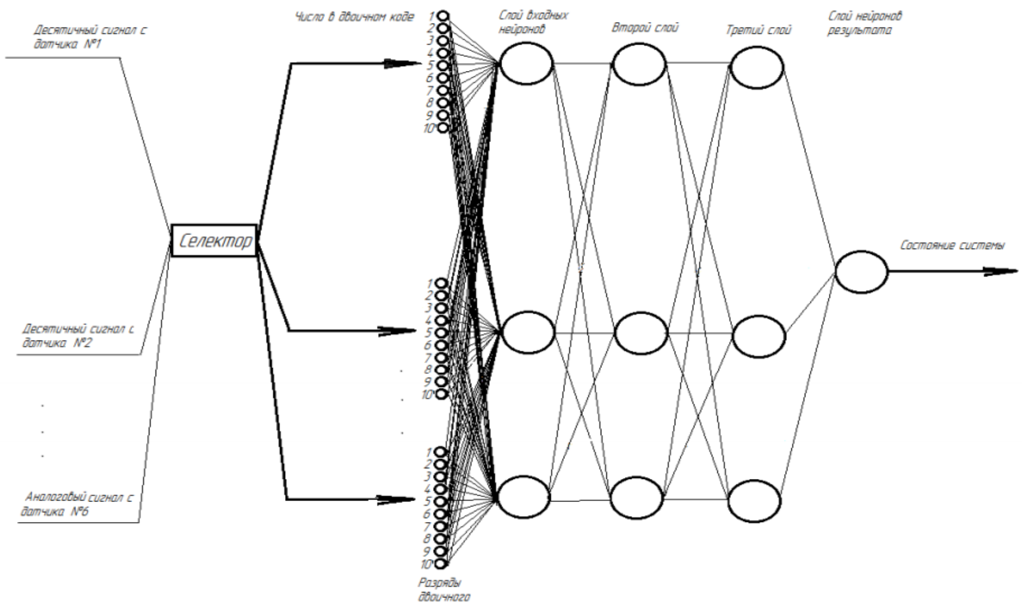

*Fig.4. **Structure of developed ANN.***

The proposed system is built on a multi-layered neural network of direct distribution with a sigmoid activation function, which will allow assessing the technological state of crushing equipment by analyzing the data of sensors, where the current training algorithm is an error back –propagation algorithm (figure. 4). The development is based on the Rozenblatt perceptron with connections between layers "all with all" through consistently operating system of sequential sensor data collection. It is also important to note that ANN performance is determined by algorithmization of the diagnostic system, as well as the level of development of a formal model of decision-making and their subsequent assessment.

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