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IMPROVING THE PROCESS OF HEATING THE BANDAGES OF LARGE COMPOSITE ROLLING ROLLS TO BE DISMANTLED

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One of the directions which ensures a significant economic effect in resource- and energy-intensive technologies is the process of restoring the large-sized composite rolls for rolling mills. The defining operation of this process is the separation of the mating bandage and the roll’s axis by thermal action on the embracing part. The general principles and results of the development, research and creation of an improved technological process for heating the products under study in a high-speed heating furnace have been described.

An integrated approach to solving the problem, based on theoretical and experimental studies, made it possible to develop a mathematical model of the process of dismantling large-sized composite rolls by thermal action on the basis of the put forward hypothesis and preliminary results of laboratory studies.

The development of the mathematical model is based on the process of rotation of the roll when it is being heated in the furnace and the subsequent dismantling of the bandage from the axis of the composite roll.

The methods of modeling the multi-mass electromechanical systems in relation to the drive of a high-speed heating furnace have been analyzed.

The dynamic model of the process of opening the bandage has been investigated and analyzed. Preliminary results have been obtained that characterize the operation of a dynamic system.

The expediency of subsequent research and development of the control system for the optimal performing of the heating process of the roll has been established.

Key words: composite rolls; thermal dismantling; heating furnaces; automatic control

Лебідь В. Т., Залятов А. Ф. «Удосконалення процесу нагріву бандажів великогабаритних складених вальцювальних валків, які підлягають демонтажу»

Одним з напрямків, що забезпечує значний економічний ефект в ресурсо- та енергоємних технологіях є процес відновлення великогабаритних складених прокатних валків. Визначальною операцією цього процесу є роз'єднання пов'язаних бандажа та вісі виробу шляхом термодії на їх охоплюючу деталь. Викладено загальні положення і результати розробки, дослідження і створення вдосконаленого технологічного процесу нагріву досліджуваних виробів в печі швидкісного нагріву.

Комплексний підхід до вирішення завдання, що базується на теоретичних і експериментальних дослідженнях дозволив розробити математичний модель процесу демонтажу великогабаритних складених валків термодією на підставі висунутої гіпотези і попередніх результатів виконаних лабораторних досліджень.

В основу розробки математичних моделі покладено процес обертання валка при його нагріванні в печі і подальшого демонтажу бандажа з осі складеного виробу.

Проаналізовано методи моделювання багатомасових електромеханічних систем стосовно приводу печі швидкісного нагріву.

Досліджено та проаналізовано динамічна модель процесу розкриття бандажа. Отримані попередні результати, які характеризують роботу динамічної системи.

Встановлено доцільність подальшого виконання досліджень і розробки системи управління для оптимального проведення процесу нагріву вироба.

Ключові слова: складені валки; термічний демонтаж термодією; опалювальні печі; автоматичне управління

Лебедь В. Т., Залятов А. Ф. «Совершенствование процесса нагрева бандажей крупногабаритных составных прокатных валков, подлежащих демонтажу»

Одним из направлений, обеспечивающим значительный экономический эффект в ресурсо- и энергоемких технологиях является процесс восстановления крупногабаритных составных прокатных валков. Определяющей операцией этого процесса является разъединение сопряженных бандажа и оси изделия путем термовоздействия на нх охватывающую деталь. Изложены общие положення и результаты разработки, исследования и создания усовершенствованного технологического процесса нагрева изучаемых изделий в печи скоростного нагрева.

Комплексный подход к решению задачи, базирующийся на теоретических и экспериментальных исследованиях позволил разработать математичну модель процесса демонтажа крупногабаритных составных валков термовоздействием на основании выдвинутой гипотизы и предварительных результатах выполненных лабораторных исследований.

В основу разработки математичной модели положен процесс вращения валка при его нагревании в печи и последующего демонтажа бандажа с оси составного изделия.

Проанализированы методы моделирования многомассовых электромеханических систем применительно к приводу печи скоростного нагрева. Исследована и проанализована динамическая модель процесса разкрытия бандажа.

Получены предварительные результаты, которые характеризуют работу динамической системы.

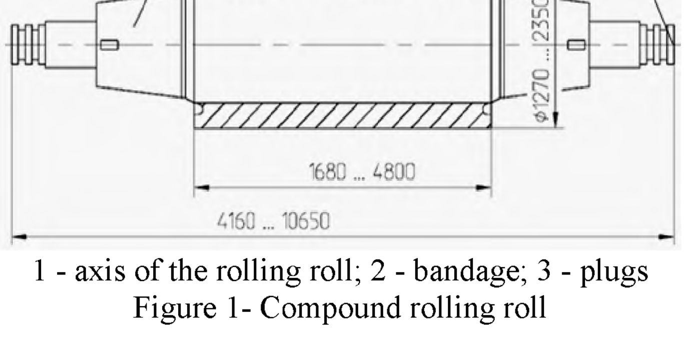
Установлена целесообразность последующего выполнения исследований и разработки системы управления для оптимального проведения процесса нагрева изделия.

Ключевые слова: составные валки; демонтаж термовоздействием; нагревательные печи; автоматическое управление

1. Relevance of the work

One of the effective areas related to resource - and energy-intensive technologies is the process of restoring the heavy-weight products related to bodies of rotation [1].

These are, for example, Large-sized Composite Rolling Rolls (LSCR) (Fig. 1), which have worked out their resources and can be the subject to subsequent restoration or can be used as high-quality billets.



1 - axis of the rolling roll; 2 - bandage; 3 - plugs
Figure 1- Compound rolling roll

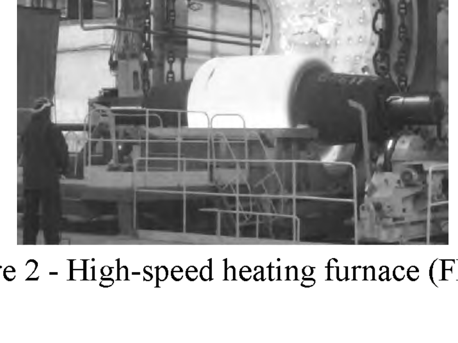


Figure 2 - High-speed heating furnace (FHF)

2. Purpose and objectives of the article

The aim of the research was the development, research and creation of an improved technological process for heating process LSCR in a fast heating furnace (FHF) (Fig. 2) for dismantling.

At the same time, the creation of a control system was considered for this process with a help of information-measuring control system for the disclosure of the embraced and embracing parts (EEP) of the LSCR in FHF for the subsequent dismantling of this product [2].

In accordance with the set goal, the following was accomplished:

1). Analysis of the heating functions under consideration of the LSCR in FHF [3].

2). The developments of physical and mathematical models of the process for disclosing of the mating parts during heating of LSCR in FHF;

3). Mathematical modeling of the heating process of LSCR for dismantling;

4). Experimental system for controlling the separation of EEP.

Scientific novelty lies in:

1) Putting forward a theoretical hypothesis of the process of heating the bandage of the composite product in the FHF for its dismantling;

2) The confirmation of theoretical developments by experimental studies.

The introduction of the developed measuring system will increase the efficiency of dismantling of composite heavy weight rolls (CHWR) for the entire range of sizes that can be placed in the FHF [5].

Theoretical and experimental studies based on the hypothesis [4, 5], which has been put forward about the change in the position of the center of bandage's mass relative to its axis, will make it possible to further optimize the process of thermal dismantling.

The results of the research will allow:

- to lay the groundwork for the development of an intelligent control system for the displacement of the center of mass of the bandage during the heating and disclosure process of the EEP of the composite rolls;
- to monitor and register a number of parameters of the heating operation in real time to display the process on the monitor of the operator's panel.

This allows to ensure a significant reduction in energy consumption for heating operations in the furnace.

The object of the research is the process of heating the bandage LSCR in FHF.

The practical value of the research lies in the development of a mathematical model and the creation of the basic prerequisites for the subsequent development of a measuring system that allows you to control the process of opening the EEP when heating the bandage in the FHF. This will make it possible to lay down the basic provisions for controlling the process of heating of the bandage in FHF when the process will be implemented in an industrial environment.

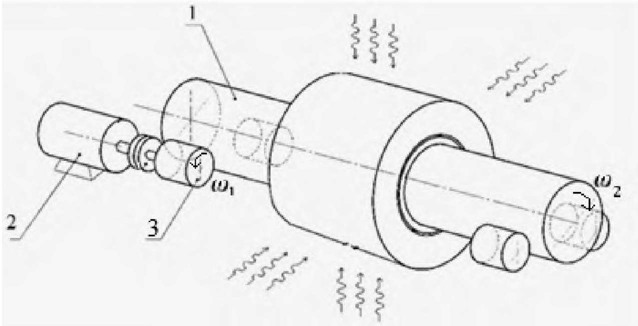
3. Analysis of published literature

A search on the topic of research performed in the scientific and technical information environment of the countries of Great Britain, Germany, Italy, Russia, the USA, France, the Czech Republic, and Japan showed that there are partial studies on the reuse of equivalent standard sizes of composite rolls, as well as the use of composite rolls with a set of interchangeable bandages at some foreign enterprises (for example, Union Electric Steel (USA), Kobe Steel (Japan)) [1, 6-9].. Given the results of a patent search, having studied the solutions found for thermal dismantling of such products, it is acceptable to conclude that this topic of research in heavy engineering is important.

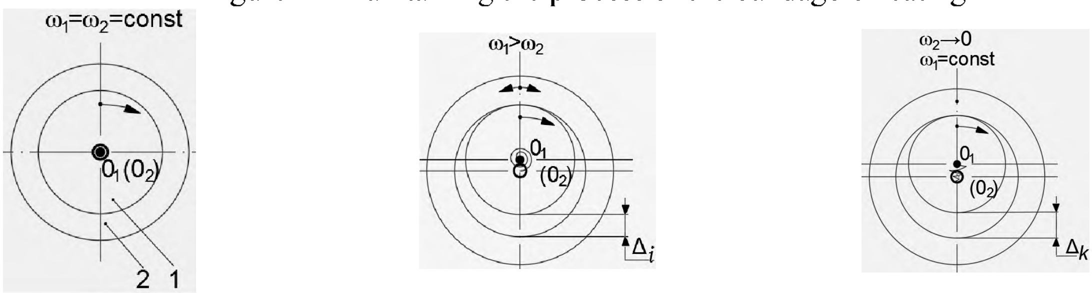
4. The main part

In the process of heating a uniform rotating bandage in the FHF (Fig. 3), its inner diameter undergo changes.

In this case, the positions of the center of the bandage's axis relative to the center of the axis of the roll and the speed of rotation (rotation) of the bandage (2) relative to the center of the axis of the roll (1) are being changed (Fig.3).



1 - composite roll, 2 - electric motor, 3 - driving roller
Figure 3 - Maintaining the process of the bandage's heating



a *b* *c*

1 - axis of the roll; 2 – bandage
a- condition of the product before heating the bandage CHWR; *b*- in the process of heating the bandage; *c* - the position of the heated bandage on the roll's axis at the final stage;
Δ_i - is the intermediate clearance; Δ_k - is the final value of the gap.
Figure 4 - Changing the position of the center of mass of the parts of the composite roll during heating of the bandage in the FHF

Consideration of the technological process of dismantling a large composite roll under the influence of heating in the FHF is represented by three interacting subsystems: 1) a bandage and 2) the axis of the composite roll; 3) an electric drive of the FHF rotation mechanism.

The structure of the model is presented in two parts: the electric, which includes the control system, electric drive, feedback sensors, and mechanical part consisting of a bandage and the axis of the composite roll [9].

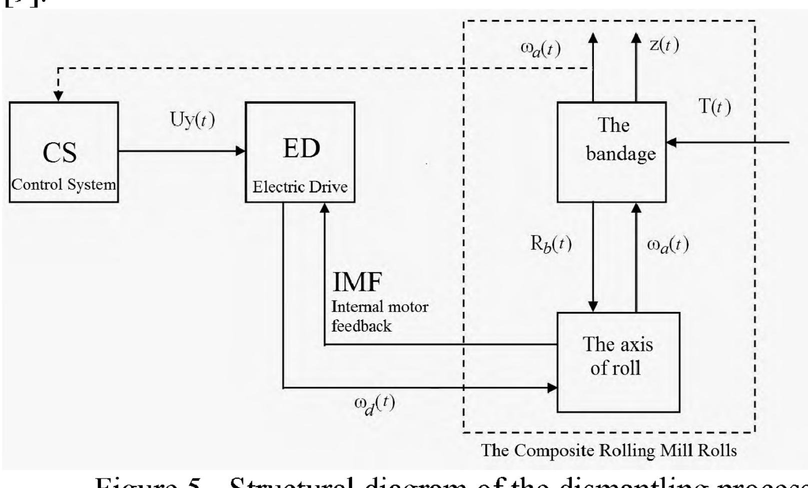


Figure 5 - Structural diagram of the dismantling process

The considered structural diagram of the technological process (Fig. 5) allows you to build a physical and mathematical model of the process of heating the bandage for dismantling the composite roll. To implement the mathematical model, analytical [10, 11] and experimental methods have been used [12, 13]. The analytical method allows to create a computational-theoretical model of the processes occurring in the object under scrutiny in accordance with the equations which describe the physical laws. The coefficients of these equations are the physical parameters obtained by theoretical research and characterize the object and the working processes in it: - structural elements of the object; - parameters of the working body; - heat transfer coefficients, etc. The model under consideration allows us to reveal the physical essence of the main stages of the process under study and analyze the change in the parameters of the EEP and the course of the heating operation [4, 5].

Due to the lack of the possibility to measure directly the controlled parameters of the reliability of these process characteristics and calculating the values of the coefficients, difficulties arise when describing the equations. The equations describing electric and thermal parameters are derived on the basis of the known design parameters and characteristics of a theoretical analysis of the processes which occur in the object under scrutiny. The experimental part of the simulation is to obtain the transient characteristics of the object.

During the implementation of the FHF heating process, the composite roll band is heated in the HSHF.

It is known [14] that the diameter of the bandage varies according to the linear law:

$$d_1 = d \cdot (1 + a \cdot T),$$

where d_1 -is the diameter of the bandage under the influence of temperature t;

d -is the output diameter of the bandage;

a- is the coefficient of linear expansion of the metal (for steel $13.1 * 10^{-6}$);

b- T - heating temperature, °C

The gap $Z(t)$ between the bandage and the axis of the composite roll can be determined by the formula:

$$Z(t) = d_1(t) - d$$

The speed of rotation of the bandage depends on the speed of rotation of the CHWR and the contact area of the connected inner surfaces of the axle and the bandage [15 – 17]. The equations of the process under scrutiny have the form:

$$\omega_Б(t) = \left| \begin{array}{ll} \omega_В & a(t) < a_p \\ \omega_В \cdot \dfrac{k}{T_1 p^2 + T_2 \cdot p + 1} & Z < Z_k,\ a(t) \ge a_p, \\ \omega_В \cdot \left(1 - \dfrac{1}{T_1 p^2 + T_2 \cdot p + 1}\right) & Z \ge Z_k \end{array} \right.$$

where k –is the gain and

T_1 and T_2 - time constant of the electric part of the drive;

$\omega_Б$ and $\omega_В$ - the speed of the bandage and roll respectively;

a_P - the opening angle at which the area of contact of the inner surface of the bandage with the surface of the roll does not provide rigidity;

Z_K - the required gap value.

When operating an electric motor, the torque of the motor must balance the static resistance of the working machine and the dynamic torque caused by the inertia of the moving masses. The equation of moments of the electric drive can be written in the form:

$$M = M_C + M_{ДИН},$$

where M - moment of the electric motor;

M_C - static moment of resistance;

$M_{ДИН}$ - dynamic moment.

Dynamic or inertial moment, as you know from mechanics, is equal to:

$$M_{ДИН} = J \cdot \frac{d\omega}{dt},$$

where J -is the moment of inertia of the moving masses, reduced to the motor shaft, kg / m^2; ω - angular speed of the motor shaft, c^{-1}.

The moment of inertia of the bandage changes in time due to the change in the inner diameter of the bandage:

$$M = M_C + M_{ДИН},$$

$$J_Б(t) = \frac{1}{2} \cdot m_Б \cdot \left(R^2 + \left({d_1(t)}/{2} \right)^2 \right),$$

where $m_Б$ - mass of the bandage.

In the Laplace formula, the velocity equation can be expressed as:

$$\omega(p) = \frac{M_Д(p) - M_P(p)}{J \cdot p},$$

where M_P - the moment that takes into account the process of disclosure. Asynchronous motor equations have the form:

$$\omega_B(p) = \frac{M(p) - M_C(p) - M_P(p)}{J \cdot p},$$

$$M(p) = \frac{\omega_0 - \omega_B(p)}{T_Э \cdot p + 1}.$$

Fig. 6 shows the model of the drive. Experimental studies were conducted on a personal computer using the Mat Lab software application.

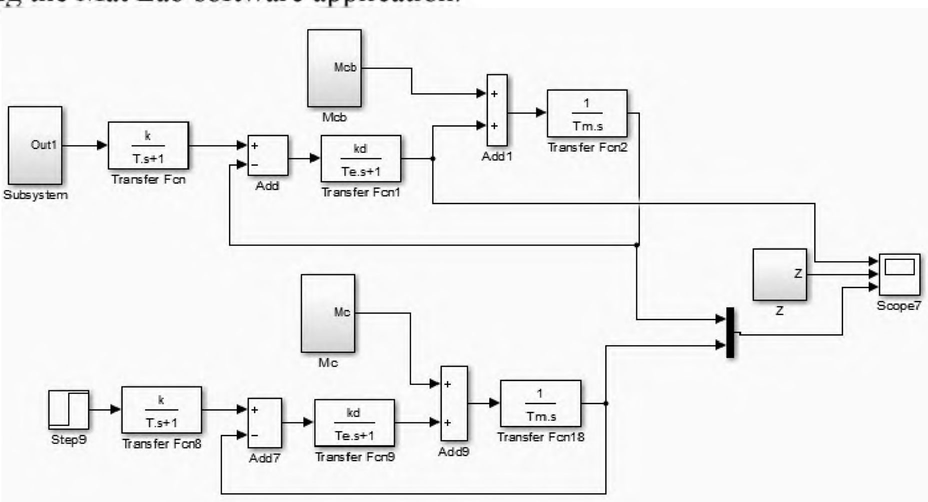


Figure 6 - Mathematical model of the drive

Fig. 8, 9 summarize the results obtained in the simulation. The dependence of the opening angle on the current gap value Δ is established. As an example, a composite at mill roll of a thick-sheet mill has been considered.

A number of basic discrete values of the diameter of the bandage during its heating were determined $D_{1..5}$ = 1201.0mm (*a*); 1201.5mm (*b*); 1202.0mm (*c*); 1203.0mm (*d*); 1204.0mm (*f*); where *d* = 1000 mm is the nominal diameter of the fitting surface of the roll axis (Fig. 7).

According to the analysis (Fig. 7), its diameter increases during the heating of the bandage, and in the result of which, the contact area of the mating surfaces of the bodies of revolution decreases and oscillations of the embracing part of the product appear, which disappear after the for-

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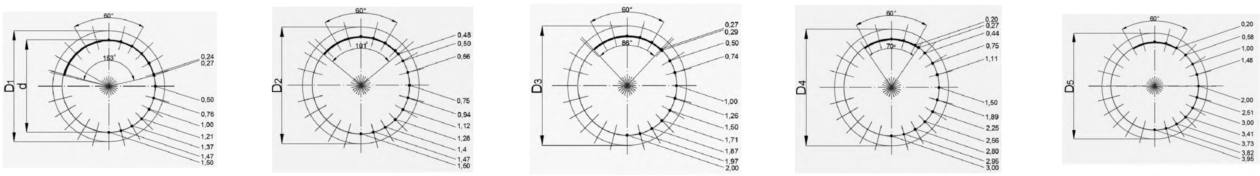
mation of the required gap is completed (Fig. 8) The results of technical solutions for the automation of this process are reflected in the following works [18- 21].



a *b* *c* *d* *f*

Figure 7- The calculated angle of the contact surface of the bandage and the axis of the roll when changing the diameter of the bandage during its heating

For step-by-step confirmation (or refutation) of the theoretical hypothesis of the trajectory of motion of the center of mass of the bandage relative to the center of mass of the axle and to test the possibility of fixing the disconnection of the EEP using IR sensors, an experimental facility was created.

The industrial facility (Fig. 9) consists of a FHF model (which includes a frame, electric motor, a clutch and support rollers) and a LSCR model (roll axis and four interchangeable bushings).

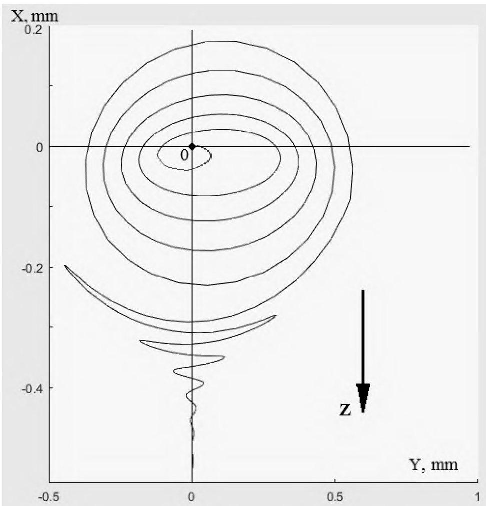


Figure 8 - The trajectory of the center of mass of the bandage at changing the inner diameter

The product under study is a model of LSCR in a ratio of 1:20.

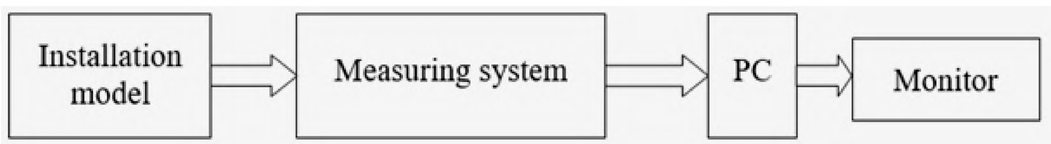


Figure 9 - Block diagram of the experimental model

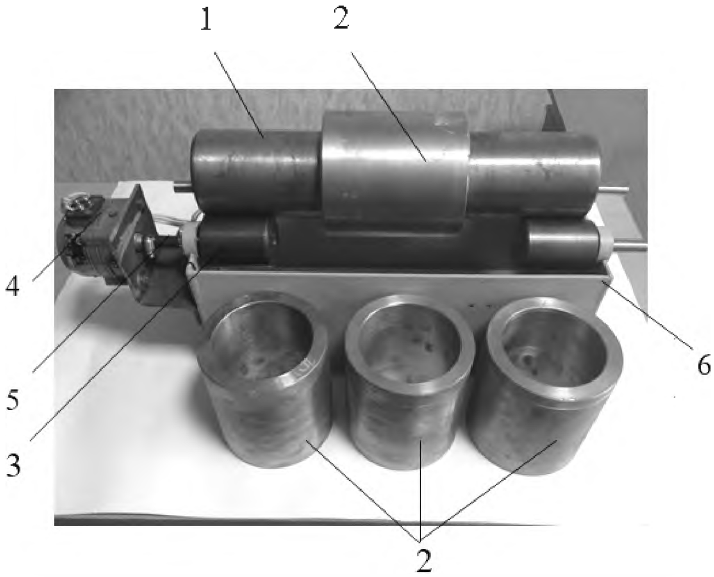
During the implementation of the technological process rotating bandage LSCR is heated in FHF. In the laboratory conditions of the department it is not possible to perform diameters, based on the calculation of the linear expansion of metal at 100, 200, 300 degrees Celsius.

In the general version, the LSCR model has the following characteristics: axle length - 422 mm; diameter - 100 mm and its mass - 25 kg; length of the sleeve - 140 mm and its inner diameter, mm: 100.0 (with tension); 100.1 (for temperatures 100^{o} C); 100.4 (200°C); 100.8 (300^{o}C), respectively; its outer diameter is 121 mm; weight of one bushing 8.8 kg.

The rotation of the axis is provided by rollers on which the axis of the model of the composite roller. One of the rollers is connected to the RD-09A motor via the clutch (Fig. 10). The electric motor ensures four revolutions per minute, which is the closest to the actual technological process. The industrial installation model is shown in Fig. 10.

In the laboratory conditions of the department it is not possible to perform heating, therefore, to simulate the expansion of the bandage under the influence of high temperatures (up to 920°C) bushings were made, with different internal.

The characteristics of the engine are given in table 1.



1 – roll axis; 2 – bandage; 3 – support rollers; 4 – electric motor PD-09A; 5 – coupling; 6 – frame

Figure 10 – Industrial plant model

Table 1 - Characteristics of the RD-09A electric motor

Parameter	Value
Power supply voltage, V	127
Frequency, Hz	50
Idle current, A	0,1
Frequency of revolutions, rpm	1200
Power, W	10
Reduction	1/137

For the processing of information, measurements and data transmission to the I / O device, a measuring system is created, which is shown in Fig. 11.

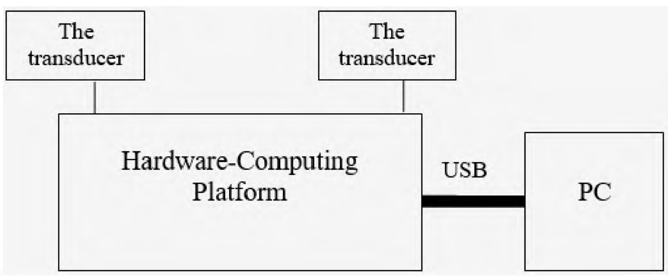


Figure 11 – Structural diagram of the measuring system

Based on the functionality of the installation, the Arduino UNO board was chosen as the hardware and computing platform. The choice is due to the fact that the board in its design has already a power controller, a microcontroller, a programmer, interfaces for connecting devices (Fig. 12) and software libraries, which facilitate the work of creating the measuring system. At the conceptual level, all boards are programmed via RS-232 (serial connection), but the implementation of this method is different depending on the version. The Serial Arduino board contains a simple inverted circuit for converting RS-232 signal levels. Current boards, such as Diecimila, are programmed via USB due to USB- to -serial converter chip. The Arduino Integrated Development Environment is a cross-platform Java application that includes a code editor, a compiler and a firmware transmission module [22].

Based on the block diagram (Fig. 11), sensors are selected that will measure the position of the centers of mass of the bandage and the axis of the roll relative to each other. The choice of sensors is due to the accuracy of the input data conversion to the output, the range of measurement, optimal geometric parameters and mass, the reliability of installation and operation cost.

The Arduino Integrated Development Environment compares two types of TCRT5000 and SHARP-GP2Y0A710K0F sensors by the above criteria. It is stated that TCRT5000 corresponds to the experimental setup better than the SHARP-GP2Y0A710K0F. In the table 2 their characteristics are shown.

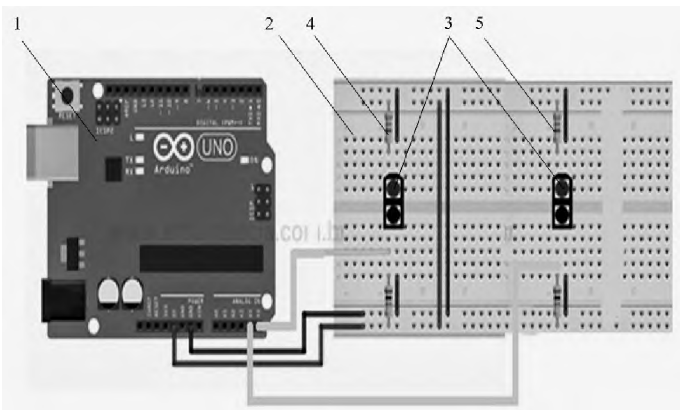
Table 2 - Sensor characteristics

Parameter	TCRT5000	SHARP-GP2Y0A710K0F
Range, mm	1-15	1000-5500
Accuracy, mm	0.2	0.3
Dimensions, mm	7x7x12	58.0 x 17.6 x 22.5
The cost is $	0.8	11.2

The distance to the object by the sensor is determined by triangulation. The light pulse (in the IR range: 850 ± 70 nm [23]) is emitted and reflected back from the obstacle. The angle of falling the light beam depends on the distance to the reflecting object. Triangulation works by detecting this reflected beam and identifying a reflection angle from which the distance is determined.

The measurement system of the experimental unit should be flexible to certain changes, namely: adding more sensors to the system; changing the positions of the sensors relative to each other; the change of sensor connections. Therefore, it is advisable to use a circuit board on which all the elements are fixed without soldering and are connected by wires.

The diagram of connection of the sensor to the Arduino board is shown in Fig. 12.

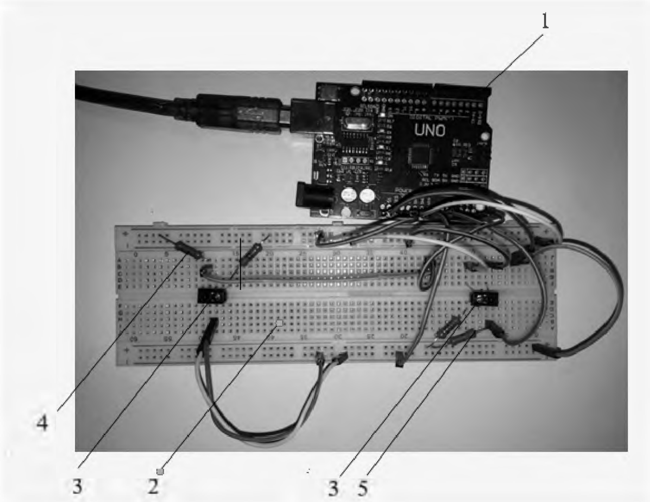


1 – Arduino hardware and computing platform; 2 – bread board;

3 – IR sensors; 4 – resistance 510 Om; 5 – resistance 10 Kom

Figure 12 – Circuit for connecting of sensors to the board Arduino

The measurement system is shown in fig. 13.



1 – Arduino hardware and computing platform; 2 – bread board;

3 – IR sensors; 4 – resistance 510 Om; 5 – resistance 10 Kom

Figure 13 – Measuring system

Considering the above, a program has been created that measures the output voltage from the sensor (0 ... 5 V) and converts it to a numerical distance value based on the characteristics of the sensor.

The general view of the experimental unit is shown in Fig. 14

This ensured the connection of the board to the sensors and obtaining the values. Since Arduino is one of the most convenient ways of programming the tools on microcontrollers, the device programming language is based on C / C ++ [22]. Any Arduino application has two required functions: setup () and loop (). The Setup () function is started once, after each connection to power. This function is used to initialize variables, to set the mode of operation of digital ports etc.

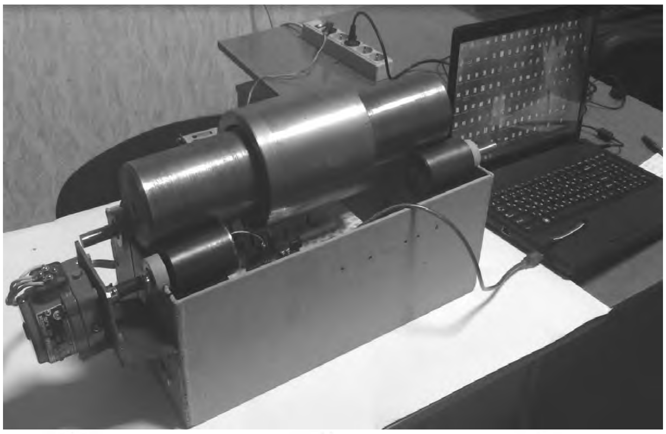


Figure 14 - General view of the experimental setup.

An Arduino board was programmed for the experimental studies on the installation.

The above function initializes the required variables of type double (floating point variables are larger than the normal float variables). In these function analog ports 0 and 5 are started to which sensors are connected [22]. The loop () function in an infinite loop consistently executes the commands described in its hardware. This means that when the function is completed, it will be called again [19]. In this function, the variables declared above, are assigned values which come to ports 0 and 5 from the sensors.

The values range from 0 to 1024, since Arduino has an ADC (bit-to-digital converter) of bit depth 10.

After the values are received, data is transmitted via the COM port. Since there are two sensors in the experimental setup, the decision has been taken to divide values by the symbol "$». Based on the above, we have the initial program algorithm for the Arduino board shown in Fig. 15.

It is known [23], that infrared sensors are sufficiently sensitive to environmental factors (light, heat, etc.), which results in inaccurate readings (up to 25%). The sensors are planned to be installed directly under the rotating shaft, which rotates and this adds such an exciting factor as vibration. Based on the above, it was decided to introduce a signal filter for the board into the program.

The Kalman filter (FC) [24] is an efficient recursive filter that estimates the state vector of a dynamic system using a series of incomplete and noisy measurements.

The algorithm operates in two stages. At the stage of forecasting, the FC extrapolates the values of the state variables as well as their uncertainties. At the second stage, according to the measurement results, the extrapolation result is specified. Due to the step-by-step nature of the algorithm, it is possible to track the state of an object in real time (using only current measurements and information about the previous state and its uncertainty). Based on the above, it was decided to implement the FC programmatically. Since the information comes from two sensors in the experimental setup, both signals need to be filtered.

Software FC is implemented separately from the sensor located under the axis of the shaft and for the sensor which is to be mounted under the bandage of the shaft. The average deviation is calculated in Excel. The function calculates the average deviation from the column (A) into which the unfiltered values from the sensors are to be entered.

The rate of response to change the values is to be set by the experimenter, based on the requirements for the time of the experiment, and it is 0.05. After the introduction of FC to the Arduino hardware and computing platform, we have the final version of the program algorithm for Arduino (Fig. 16).

A complete code listing for the Arduino hardware platform has been developed. Microsoft's Visual Studio 2010 solution has been chosen as the development environment. It is planned to create software in Visual Basic .NET [25].

A complete code listing of the software for the hardware has been developed. This language is based on a .NET framework (works with CLR), and a programming language has also been developed.

Considering the advantages and disadvantages of VB.NET programming language, it was decided to synthesize software for experimental installation in VB.NET. Based on the functionality of the program, an algorithm for the future software product has been created (Fig. 17).

Based on the functionality of the program, it was decided to create an experimenter's workplace (program interface).

The automated workplace (AWP) should contain the following components: fields for entering geometric data of the study object and experiment number; fields for selecting the connection port and data rate; element of graphic image of received data; information about the time of the experiment; experiment start button. The picture of the workplace is shown in Fig. 18.

Based on the functionality of the program, we built the algorithm. A serial port is used to communicate between the board and the PC. On this basis, we will add to the program the element SerialPort, which is a serial connection resource.

The project folder already has a database in which it is planned to store the values obtained during the experiment. Once connected to the board, a table is created in the database. The table name consists of information such as the experiment number and the date and time of the experiment. After that, the Splter and Splter Two functions separate the value of the sensor under the axis from the value of the sensor under the bandage, separated by the symbol "$".

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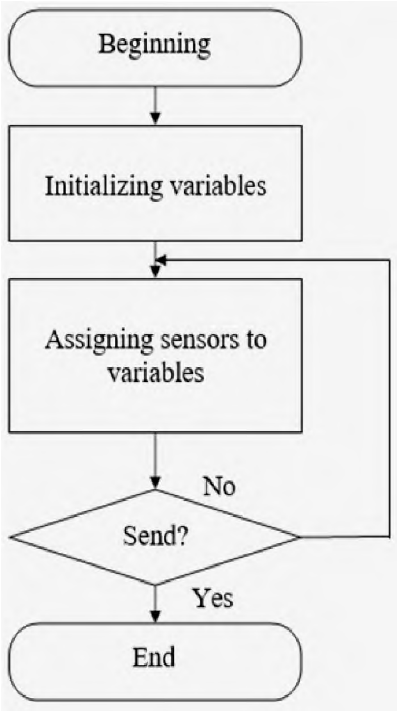

Figure 15 - Initial program algorithm for the Arduino platform

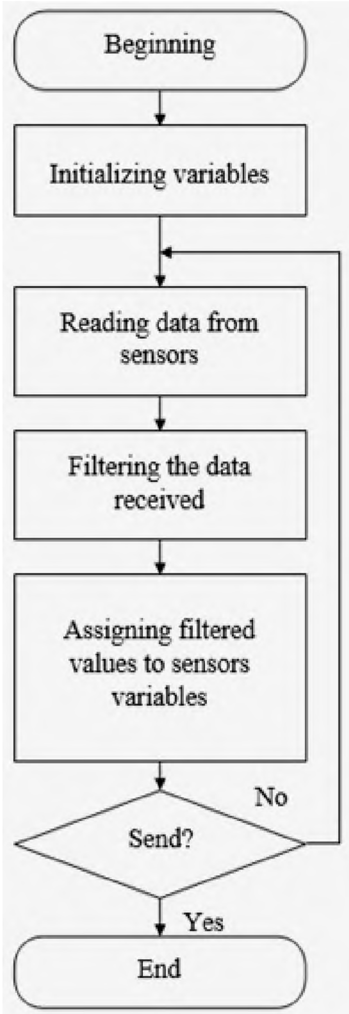

Figure 16 - The final version of the program algorithm for Arduino

The program ignores if the data from the board is more than 1024. This allows you to separate the erroneous reading of unnecessary signals. Otherwise, a point is created on the graph (the value of the sensors relative to time), and the process is repeated again. It also records to the database where the result of the experiment, axis and bandage parameters, experiment number and time are recorded. The distance between EEP is determined mathematically by looking at the value from the board. Full program code listing has been developed.

At the first stage of the experiment, a roll with a bandage is to be installed the inside diameter of which was 100.0 mm. The valid interval of the first stage of the experiment is 0.02 mm.

Based on the data obtained during the experiment, it was found that the measurement error at this stage was up to 22 %.

The previous obtained values testify that it is possible to measure the separation of the roller axis and the bandage by the developed measuring system.

For further (complete) verification it is advisable to make a number of changes to the measuring system, for example, to increase the number of sensors (up to eight); to use a higher bit analog digital converter (ADC); install the sensors at an angle of 45^o relative to each other along the forming (forming) surface of the bandage.

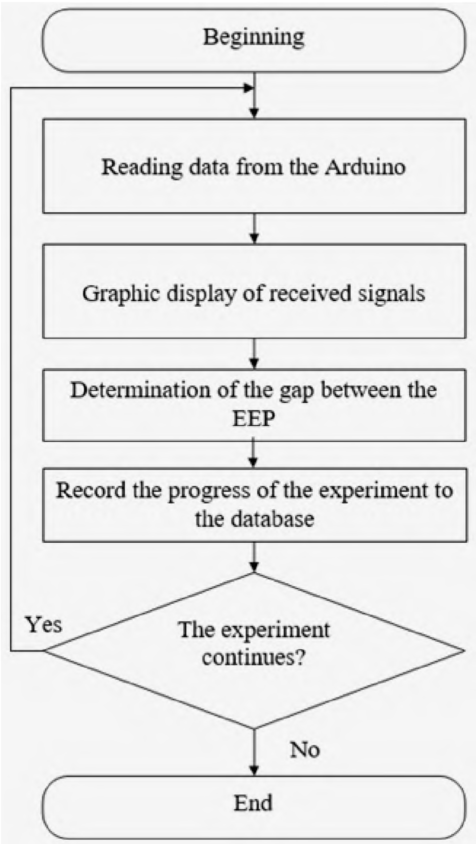

Figure 17 - The algorithm of the program for processing data from the Arduino card on the computer

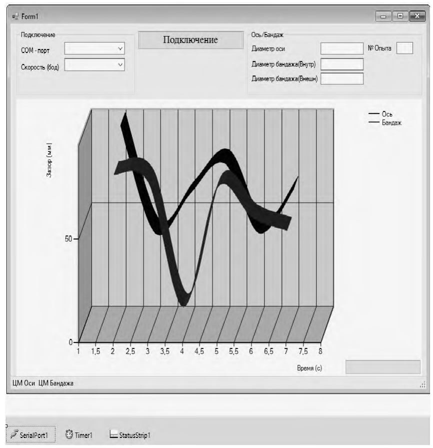

Figure 18 - The experimenter's AWP

5. Conclusions

1. A review and analysis of the sources of technical information, as well as the market for raw materials and capabilities of potential customers, shows that in the process of reuse of dismantled parts of the LSCR there is a large reserve of savings.

2. It is established that due to the existing technology of dismantling the LSCR, the machine-building enterprises can obtain parts for the restoration of the rolls; high quality workpieces for rolls of smaller size; high quality workpieces for various other parts.

3. The stage of heating of the rolls for further process of dismantling was considered and performed on the basis of modern methods of automation (to control the disengagement of the conjugated surfaces) based on the use of new equipment (partially, FHF), which ensures increased profitability of operations of disassembly and improvement the quality of service.

4. In order to test the theoretical hypothesis, an experimental setup has been developed, consisting of FHF and CHWR models with ratio to 1:20. To simulate the expansion of the bandage under the influence of high temperatures were made bushings (bandages), with different internal diameters, based on the formula of linear expansion of the metal for 100, 200, 300 degrees Celsius, respectively.

5. A measuring system has been developed, consisting of: Arduino hardware and computing platform; two TCRT5000 sensors (one sensor measures the position of the center of mass of the axle and the other the bandage); the motherboard; the connecting wires.

The algorithm and software have been created to ensure the connection of the board with sensors and Arduino hardware platform.

After implementing FC into Arduino hardware platform we have the final version of the algorithm of the program for Arduino.

Experimenter AWP has been developed to provide visualization of the experiment process, logging and recording of the data obtained. Additionally the software in Visual Basic. NET has been developed.

Experimental studies have shown that this measuring system works correctly, responding to changes in bandage diameters. Accuracy, at this stage – up to 30%.

6. According to the received experimental data recommendations are made up for the design of an industrial installation. The automatic industrial installation system must consist of two S7-300 series programmable controllers; two Sinamics G120 frequency adjustable actuators; switching and relay contactor equipment. The installation must guarantee measurement accuracy of up to 1.5% and reliability of up to 90%.

7. Based on received calculations, which show that the biggest economic benefit is achieved due to roll restoration depending on sizes and energy savings.

The economic effect of re-assembling of the component supporting rolls with the restoration of the axle, on the example of the plate rolling mill of metallurgical plant with amounts to UAH 800,000.

The full economic effect consists of the economic benefit in the reconditioning of the compound support rolls and the additional economic advantage in the above mentioned sum due to the optimal heating of the bandage of the used roll.

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