

Metrological Aspects of Controlling the Rotational Movement Parameters of the Auger for Dewatering Solid Waste in a Garbage Truck

Waldemar Wójcik, Oleh V. Bereziuk, Mykhailo S. Lemeshev, Volodymyr V. Bohachuk, Leonid K. Polishchuk, Oksana Bezsmertna, Saule Smailova, and Saule Kurmagazhanova

Abstract—In the article, a device for measuring the parameters of the rotational movement of the auger for dewatering solid waste is proposed based on the analysis of signal processing methods and measurement of physical quantities. It can be used in the development of high-performance special vehicles for transporting waste as the main link in the structure of machines for the collection and primary processing of solid waste. The structural scheme of the means and block diagram of the microcontroller control program algorithm for implementation of the device for measuring the parameters of the rotational motion are proposed. The main technical characteristics of the proposed means are given. The results of experimental tests for measuring the parameters of rotational motion are shown. The results of experimental studies, which are given in the work, confirmed the reliability of the measured parameters.

Keywords—municipal solid waste; dehydration; auger; measuring; digital control

I. INTRODUCTION

THE relevance of the study of the municipal solid waste (MSW) management system is included in one of the clauses of the Association Agreement between the European Union and Ukraine [1,2]. The annual volume of solid waste in Ukrainian residential areas is more than 46 million cubic meters per year [3]. Among the technologies of solid waste management in Ukraine, landfills and dumps are the most common (96.5%). Only during 1999-2014, the total area of landfills and dumps in Ukraine increased 3 times. Also, the area of overloaded landfills has almost doubled and more than 3.1 times increased the area of those landfills and dumps that do not meet environmental safety standards, including due to soil contamination with leachate, which can get into groundwater, polluting it. Collection and transportation of solid waste to landfills and incineration sites is carried out by more than 4100 garbage trucks, which are designed to compact solid waste, reducing transportation costs and the required landfill space, but at the same time incur significant financial

Waldemar Wójcik is with Lublin University of Technology, Poland (e-mail: waldemar.wojcik@pollub.pl).

Oleh Bereziuk, Mykhailo Lemeshev, Volodymyr Bohachuk, Leonid Polishchuk and Oksana Bezsmertna are with Vinnytsya National Technical University, Ukraine (e-mail: berezyukoleg@i.ua, mlemeshev@i.ua, bogachukvv64@gmail.com, leopolishchuk@gmail.com, bezsmertnaoksana@gmail.com).

Saule Smailova and Saule Kurmagazhanova are with D. Serikbayev East Kazakhstan technical university (e-mail: saule_smailova@mail.ru).

costs [3]. A scheme of hydraulic drive for dewatering and compaction of solid waste with a conical screw press in a garbage truck during its loading is proposed in [4], which allows to provide an increase in the coefficient of their sealing and reduction of their mass to be transported, directly in the places of collection, to carry out preliminary processing of waste by means of their dehydration and partially grinding, as well as, by reducing the volume and mass of MSW, significantly reduce the increase in land area allocated to landfills and landfills full of rubbish, which will lead to decrease the rate of deterioration of the environmental situation. From the values of parameters of the auger's rotational movement significantly depend the energy intensity of the technological process of dehydration MSW and their final relative humidity. Therefore, in our opinion, it is expedient to install a means for measuring the parameters of the auger's rotational movement for the dehydration of the MSW with the possibility of indication in the driver's cab for the operator to control the process of dehydration.

According to the Resolution of the Cabinet of Ministers of Ukraine No. 265 [5], ensuring the using of modern high-efficiency garbage trucks in the communal economy of the country, as the main link in the structure of ecological machines for collecting and primary processing of municipal solid waste, is a relevant scientific and technical problem. Development of means for measuring the parameters of the rotary auger's movement for the dehydration of municipal solid waste in a garbage truck is one of the important tasks for solving this problem [6].

The purpose of the research is to create a means to determine the reliability of the control parameters of auger's rotational movement for the municipal solid waste dehydration in the garbage truck based on the analysis of existing methods of signal processing and measurement of physical quantities. In the analysis of literary sources, it has been determined that many studies are based on the using of sensors and data recording systems in many fields of science and technology [7–10]. In recent years, Arduino's microcontroller boards [11, 12] have become popular for the development of digital measuring devices, which, along with many other well-known brands such as BeagleBone and RaspberryPi, are a class of small, low-cost, single-board computers, the programming and development of applications that are supported by a large community of developers and users, who provide various open source libraries, sample solutions, forums that cover various thematic and additional aspects. The advantages of Arduino



microcontrollers include low project cost, interconnection with sensors and expansion cards for more complex tasks, autonomy, low power consumption, low installation requirements, small proportions. In work [13], an inexpensive device for mobile determination of atmospheric electric field parameters, relative humidity and air temperature based on Arduino Uno with GPS function is proposed. Along with the widespread method of outputting measured data through a graphical user interface to the screen of a personal computer, it is added the opportunity to observe the results of measurements with the LCD display and a laptop computer. The general data logger for the Arduino Mega 2560 photoelectric monitoring system, which can store a large amount of data on the SD card from the input channels, is proposed in the article [14]. The scanning system for non-destructive control based on Arduino is described in work [15]. The article [16] proposes methods for the development and implementation of a low-cost remote-control system based on Arduino's energy-efficient technologies "Smart Home" with basic functions that provide comfort and safety for the residents. The system is highly flexible and scalable and can be extended to large households. The feature of this system is that the Arduino microcontroller board is connected via an economically efficient hybrid (wireless technology Zigbee and Wired – X10) communication system with an Android application through the user interface. The monograph of Bohachuk and Mokin [17] describes developed methods and created on their basis means for continuous control of the moisture content for powdered materials in the conditions of the technological process of their production. In article of Bereziuk et al., [18], a means is suggested, that allows rapid analysis to measure relative humidity during experimental studies on the dehydration of MSW, also in [19, 20].

II. METHOD

Analog and digital signal processing methods, a contact pulse method of measuring physical quantities, methods of analysis and synthesis, computer information processing, and experimentation were used for research and analysis. To convert the value of the digital signal of the incremental encoder into the value of the number of revolutions, taking into account the direction of rotation, the following conversion equation was used:

$$N = \frac{1}{k} \sum_{i=1}^m \left(\frac{U_{Ai}}{U_R} - \frac{U_{Bi}}{U_R} \right) = \frac{1}{kU_R} \sum_{i=1}^m (U_{Ai} - U_{Bi}) \quad [\text{rev.}], \quad (1)$$

where k is the number of positions of the encoder on 1 rotation; i is the current position of the encoder; m is the number of passed positions of the encoder since the start; U_R is the reference voltage (V); U_A , U_B is respectively the voltage on line A and B of the encoder (V).

The rotation speed, taking into account the direction of rotation, can be calculated by the following conversion equation

$$n_j = \frac{60 \cdot 10^6 \Delta N}{t_j - t_{j-1}} = \frac{60 \cdot 10^6}{kU_R(t_j - t_{j-1})} \sum_{i=1}^{m_{\Delta t}} (U_{Ai} - U_{Bi}) \quad [\text{rpm}], \quad (2)$$

where: j is the number of the current measurement result; t_j is the end of the interval of time during which the measurement

of frequency rotation (μs); t_{j-1} is the beginning of the interval of time during which the measurement of the frequency rotation (μs); Δt is the time interval for outputting the measurement results to the screen, (μs); $m_{\Delta t}$ is the number of passed encoder positions during the time interval for outputting the measurement results to the screen (pos.).

The angular velocity, taking into account the direction of rotation, can be calculated by the following conversion equation.

$$\omega_j = \frac{\pi n_j}{30} = \frac{2\pi \cdot 10^6}{kU_R(t_j - t_{j-1})} \sum_{i=1}^{m_{\Delta t}} (U_{Ai} - U_{Bi}) \quad [\text{rad/s}]. \quad (3)$$

The angular acceleration, taking into account the direction of rotation, can be calculated by the below conversion equation

$$\varepsilon_j = \frac{\omega_j - \omega_{j-1}}{t_j - t_{j-1}} = \frac{2\pi \cdot 10^6}{kU_R(t_j - t_{j-1})^2} \left[\sum_{i=1}^{m_{\Delta t}} (U_{Aji} - U_{Bji}) - \sum_{i=1}^{m_{(j-1)\Delta t}} (U_{A(j-1)i} - U_{B(j-1)i}) \right] \quad [\text{rad/s}^2]. \quad (4)$$

The total error of reproduction of the actual values of the parameters of rotational motion consists of systematic and random errors of the elements of the measuring channel and can be determined using following quadratic dependence,

$$\delta_{\Sigma} = \sqrt{\delta_{in}^2 + \delta_{dn}^2 + \delta_{qe}^2 + \delta_{ce}^2 + \delta_{ze}^2} \quad [\%], \quad (5)$$

where δ_{in} is the integral nonlinearity (%); δ_{dn} is the differential nonlinearity (%); δ_{qe} is the quantization error (%); δ_{ce} is the conversion factor error (%); δ_{ze} is the zero bias error (%).

The datasheet for the ATmega328 microcontroller [21] provides the values of individual accuracy parameters. Integral nonlinearity characterizes the deviation of the real ADC characteristic from the ideal one in the middle of the quantization step and is no more than 0.5 units of the least significant bit, i.e. 0.05%. Differential nonlinearity characterizes the deviation between the centers of adjacent quantization steps on the real and ideal characteristics and is no more than 0.25 units of the least significant digit, i.e. 0.025%. The error of the conversion coefficient shows how the slope of the line between the first and last points of the real conversion characteristic corresponds to the ideal value and is no more than 2 lowest digit units, i.e. 0.2%. The zero offset error indicates the value of the signal at the ADC input when the output code is 0 and is no more than 2 lowest bit, i.e. 0.2%.

After the mathematical transformations of expression (1), the quantization error of the rotational motion measurement device is estimated as follows.

$$\delta_{qe} = \frac{100\%}{N_{\min} k} = \frac{U_R}{\sum_{i=1}^m (U_{Ai} - U_{Bi})} 100\% \quad [\%]. \quad (6)$$

Using expression (6), we determine that the maximum quantization error of the rotational motion measurement device does not exceed 5%. Substituting the known values into expression (5), we determine that the total error of such device is 5.008%.

III. PRACTICAL REALIZATION

Figure 1 shows a block diagram of the proposed device for measuring the parameters of rotational motion, which consists of an incremental encoder (IE) equipped with a step fixer (SF), a microcontroller board (MCU), and an LCD Keypad Shield display and control module (DCM). To ensure the operation of the microcontroller, the circuit includes a clock generator G and a reference voltage source (VSS).

The microcontroller port assignment is as follows:

- port 1 – display of measurement results and control of display parameters;
- port 2 – communication with a personal computer via USB interface;
- port 3 – incremental encoder pin A input;
- port 4 – incremental encoder pin B input;
- port 5 – reference voltage input.

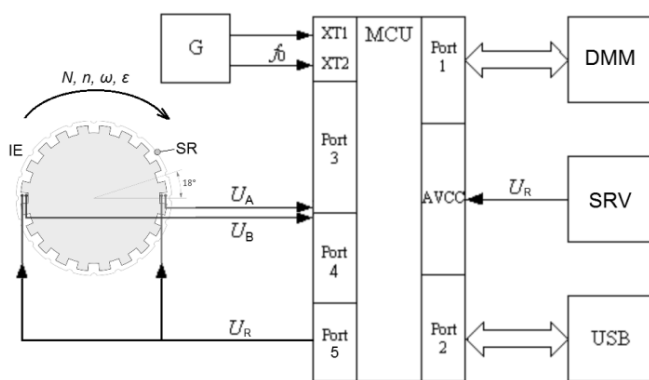


Fig. 1. The structural diagram of the means for measuring the parameters of the rotational movement

An incremental encoder (rotary angle sensor) is a device that converts the rotational movement of a shaft into a series of electrical impulses, the number of which is proportional to the angle of rotation, and which allows determining the direction and angle of rotation. Counting the number of these pulses gives the value of the angle of rotation of the encoder shaft relative to its initial position. Also, using these values, the rotation speed can be determined.

There are two types of encoders: absolute and cumulative. Absolute encoders determine the angle of rotation directly from the position of the sensor shaft. The main feature of this type of sensor is that they can determine the angle of rotation immediately upon switching on. Incremental (accumulative) ones generate pulses, the number of which can be used to determine the position of the shaft. Immediately after switching on, the position of the shaft of this type of sensor is unknown, since this type of encoder does not generate output pulses when the shaft is idle. The main feature of incremental encoders compared to absolute encoders is that they can only report the amount of change in their position, not their absolute position. Incremental encoders are the most popular sensors in applications where mechanical motion must be converted into a digital signal. The popularity of incremental sensors is due to the fact that absolute position sensors are too complex and expensive.

Encoders are very widely used in various types of devices: servo drives, robotics, electronics, mechanical engineering, computer, household and music equipment, etc. Encoders are also ideal for realizing navigation through various menus. A popular example of using an incremental encoder in everyday life is the volume knob of a car stereo. It can also be used as a digital potentiometer. Unlike potentiometers, encoders are much more reliable and do not require the use of an ADC. Unlike variable resistors, where the angle of rotation of the handle is about three quarters of a circle, a full rotation is performed here. The fundamental difference is the ability to rotate a full revolution an unlimited number of times, realizing a continuous rotary encoder.

Incremental encoders can be made as optical, magnetic, mechanical, etc. Regardless of the device principle of operation, all incremental encoders generate 2 lines (A and B) with pulses shifted with respect to each other. The pulse offset is used to determine the direction of rotation and by the number of pulses - the angle of rotation.

Each incremental encoder has the following main characteristic - resolution (the number of steps, positions between pulses, per shaft revolution). This discreteness makes it possible to calculate the angle of a single position change. In addition, the encoder shaft is fixed in each position between each sequence of pulses. The encoder determines the angle of rotation by counting the number of pulses from the start. When the encoder shaft is stationary, it is impossible to determine the angle of rotation. The encoder shaft can be rotated 360° in both directions. The encoder is based on 2 pairs of contacts and a metal plate with notches. As the shaft rotates, each pair of contacts closes and opens. However, these pairs of contacts are arranged in such a way that when the shaft rotates in different directions, the order of closing/opening of the contacts is different - identical pulse sequences are shifted by 90° relative to each other, which allows you to determine the direction of rotation.

The mechanical incremental encoder KY-040, with a switch (button) and step-by-step fixation of the shaft position between each series of pulses, is a rotary sensor that indicates the degree of rotation of the shaft and in which direction it rotates. It can be used to measure the speed and position of the drive shaft, control the angular position, angular velocity, and length of traveled distance. A rotary encoder has a fixed number of positions per rotation. These positions can be easily perceived as small clicks when the encoder shaft is rotated. This encoder module has 20 such positions, which means that 20 series of pulses are generated per full rotation. This means that each step is equivalent to a rotation of 18°. The number of such positions characterizes the sensitivity of the rotation sensor. A single rotation sensor has three outputs. They are usually labeled A, B, and C. In the case of KY-040, they are oriented as shown in Fig. 2.

There are two switches inside the encoder. The first switch connects pin A to pin C, and the second connects pin B to pin C. Each click toggles the state of the switches as follows: if both switches are closed, turning the axis clockwise or counterclockwise one position will toggle both switches open. If both are open, turning the axis clockwise or

counterclockwise by one position will switch both switches to the closed state.

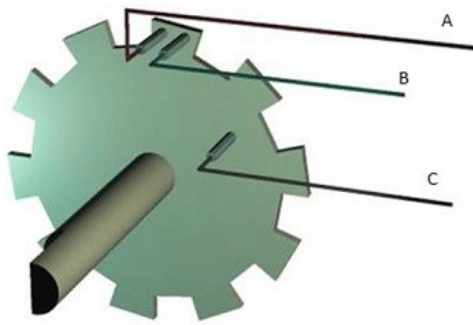


Fig. 2. The location of the IE switches KY-040

As you can see from Fig. 2, the angular position of contact A and contact B is such that a clockwise rotating plate will connect contacts A and C. A counterclockwise rotating plate will connect contacts B and C. Fig. 3 shows a graph of the transient characteristics of the contacts with uniform rotation of the encoder plate.

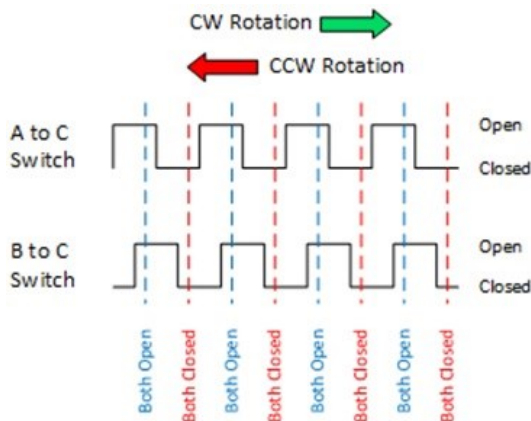


Fig. 3. Graph of transient characteristics of the contacts with equable rotation of the IE plate

The encoder has one 5-pin pin connector for power and controller connection. Power: "+" – supply voltage, GND – common (ground); data: CLK and DT – encoder outputs, pulled-up with 10kΩ resistors, SW – output signal from the button, when pressed, the pin is shorted to ground. This encoder is mechanical, no power supply is needed, yet pull-up resistors are necessary. The module is designed in such a way that a low logic level appears on the CLK and DT terminals when the contacts are closed and high when the terminals are open. A high level is generated by the pull-up resistor. The encoder can be powered either from the Arduino controller board or from an external power source. The maximum current through the encoder contacts is 10mA. To read signals from the module, you need to use two digital inputs.

To mechanically connect the sensor shaft to an external mechanism, it is necessary to use a special flexible connector (elastic coupling) designed to compensate the possible beating of the shafts, both in the radial and axial directions. This

dramatically reduces the likelihood of premature wear of the sensor shaft bearings. Even a slight play in the axial direction of the shaft can lead to a complete electrical failure of the encoder.

The sensor can be controlled from the Arduino controller board or from other microprocessor-based control device using a special program. The Arduino UNO R3 board was chosen as the controller, which is the most common version of Arduino controller boards, described in detail in [6]. [Bereziuk et al., 2018]. The block diagram of the program algorithm is shown in Fig. 4. Connection of display and control module, sensors for measuring the parameters of the rotational movement to Arduino Uno R3 board, is shown in fig. 5. The controller is programmed from the integrated software environment Arduino IDE.

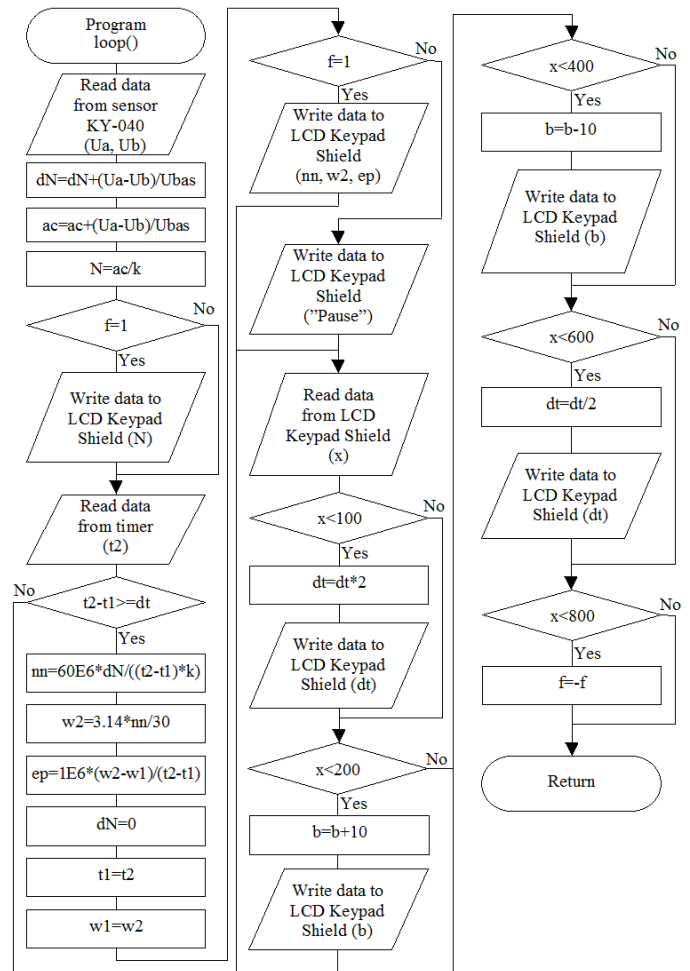


Fig. 4. Block scheme of the algorithm and the loop program

To display the results of measuring the parameters of rotational motion, we used the LCD Keypad Shield, one of the most popular expansion boards for Arduino. The RIGHT and LEFT buttons of the LCD Keypad module are used to increase and decrease, respectively, the time interval for displaying the measurement results on the screen by a factor of 2. The UP and DOWN buttons are used to increase and decrease the brightness of the screen, respectively, in order to improve the visibility of the measurement results under different lighting

conditions. The SELECT button is used to implement the pause/start function in order to fix the current values of the rotational motion parameters on the screen. Table I shows the main characteristics of the proposed tool for measuring the parameters of rotational motion.

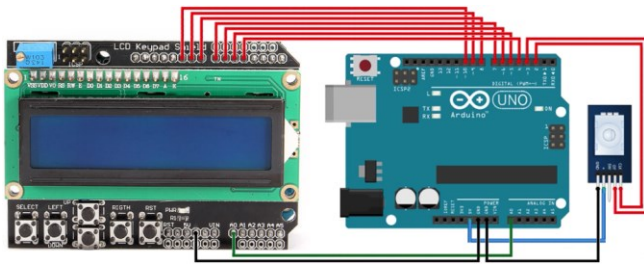


Fig. 5. Connection of the indicating and controlling module, the sensor for measuring the parameters of the rotational movement to the Arduino Uno R3 board

TABLE I
 MAIN CHARACTERISTICS OF THE PROPOSED MEANS FOR MEASURING THE PARAMETERS OF ROTATIONAL MOTION

| Parameter | Value |
|--|-----------------|
| Measuring range: | |
| - number of rotations, rot | -107...+107 |
| - rotation speed, rpm | -60000...+60000 |
| - angular velocity, rad/s | -6283...+6283 |
| - angular acceleration, rad/s ² | -31415...+31415 |
| Resolution: | |
| - number of rotations, rot | 0.05 |
| - rotation speed, rpm | 0.01 |
| - angular velocity, rad/s | 0.01 |
| - angular acceleration, rad/s ² | 0.01 |
| Measurement error, % | |
| - < 800 rpm | < 2 |
| - > 800 rpm | < 5 |
| Power supply, V: | |
| - from USB | 5 |
| - from an external power supply | 6...20 |
| Consumption current, mA, | <175 |
| Shaft diameter, mm | 6 |
| Temperature, °C: | |
| - exploitation | -30...70 |
| - storage | -40...85 |
| Interfaces | USB, LCD+Keypad |

IV. RESULTS OF EXPERIMENTS

Using the developed device for measuring the parameters of rotational motion, an experimental measurement of the rotational speed n in the range of 19...2586 rpm was carried out, the results of which are shown in Table II. Table II also shows the absolute values of the relative error $|\delta|$ of the measurement of the experimental rotational speed n_{exp} relative to the actual rotational speed n_{fact} . Figure 6 shows the graphical dependence of the absolute values of the relative error $|\delta|$ of the rotation speed measurement n .

Consequently, experimental studies have shown the suitability of the proposed method for measuring the parameters of the rotational movement of the auger for dewatering solid waste in a garbage truck.

TABLE II

RESULTS OF THE EXPERIMENT ON MEASURING THE ROTATION SPEED

| n_{fact} , rpm | n_{exp} , rpm | $ \delta $, % | n_{fact} , rpm | n_{exp} , rpm | $ \delta $, % |
|------------------|-----------------|----------------|------------------|-----------------|----------------|
| 19 | 18.76 | 1.26 | 437.7 | 441.68 | 0.91 |
| 22 | 21.85 | 0.68 | 550.3 | 541.84 | 1.54 |
| 27 | 26.51 | 1.81 | 653.7 | 647.29 | 0.98 |
| 30 | 29.78 | 0.73 | 700.5 | 693.09 | 1.06 |
| 33 | 33.18 | 0.55 | 791.6 | 778.37 | 1.67 |
| 42 | 41.22 | 1.86 | 816.7 | 836.00 | 2.36 |
| 45 | 44.21 | 1.76 | 832.0 | 822.30 | 1.17 |
| 71 | 69.82 | 1.66 | 854.0 | 836.00 | 2.11 |
| 78 | 76.51 | 1.91 | 939.9 | 933.23 | 0.71 |
| 90.3 | 90.73 | 0.48 | 989.9 | 994.95 | 0.51 |
| 121.3 | 119.50 | 1.48 | 1034 | 1015.00 | 1.84 |
| 141.4 | 139.98 | 1.00 | 1448 | 1387.64 | 4.17 |
| 214.7 | 213.19 | 0.70 | 1603 | 1568.42 | 2.16 |
| 331.6 | 330.13 | 0.44 | 2586 | 2691.00 | 4.06 |
| 367.6 | 361.79 | 1.58 | | | |

V. CONCLUSIONS

Based on the analysis of existing methods of signal processing and measurement of physical quantities, a tool is proposed that allows measuring the parameters of the rotational movement of the auger for dewatering solid waste during the development of high-performance garbage trucks as the main link in the structure of machines for the collection and primary processing of solid waste.

The structure scheme of the device and the algorithm, which allows you to control the operation of the microcontroller of the device for measuring the parameters of rotational motion were proposed.

Experimental studies have been conducted to show the suitability of the proposed means for measuring the parameters of rotational motion of the screw for dewatering solid waste in a garbage truck.

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