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THE USE OF THE ARDUINO MODULE IN CONTROLLING THE VEGETABLE INDUSTRY EQUIPMENT ON THE EXAMPLE OF A WEIGHING-PACKING MACHINE®

Zastosowanie modułu Arduino w sterowaniu urządzeniami przemysłu warzywniczego na przykładzie wagoworkownicy®

The article presents the concept and the completed prototype of a mechatronic, automated two-belt weighing-packing machine for vegetables. The solutions for the mechanical, electrical and electronic parts have been developed by the authors. The control concept was based on the Arduino programming platform and the Arduino 2560 board, while the control system itself was implemented in C++. The paper describes the structure of the machine as well as tests for checking the effectiveness of the machine for weighing potatoes in 2, 5 and 10 kg portions.

Key words: machine, weight, 3D models, system.

W artykule przedstawiono koncepcję oraz zrealizowany prototyp mechatronicznej, automatycznej dwutaśmowej wagoworkownicy do warzyw. Rozwiązania części mechanicznej, elektrycznej jak i elektronicznej zostały opracowane przez autorów. Koncepcję sterowania oparto o platformę programistyczną Arduino oraz płytkę Arduino 2560, zaś sam system sterowania zaimplementowano w języku C++. W pracy zawarto opis konstrukcji maszyny, jak i badania sprawdzające skuteczność działania maszyny dla ważenia ziemniaków w porcje 2, 5 i 10kg.

Słowa kluczowe: maszyna, waga, modele 3D, system.

INTRODUCTION

Agriculture is one of the most important parts of the world economy [8, 25, 26]. The level of mechanisation is a measure of the country's technological development [12, 16, 37]. Sustainable development of agriculture involves meeting the needs of current and future generations with particular attention to the need to harmoniously link economic, social and natural development aspects [14, 22, 28]. Operating with a full balance between socio-economic and environmental factors is a challenge that will be faced by farmers and food producers in the coming years [24, 33, 36]. Farmers and agricultural entrepreneurs more and more often invest financial resources in equipment based on solutions that enable rationalisation of the use of means of production, monitoring of crops, animals and machinery, and at the same time support production and business decisions [3, 23, 32].

The agri-food sector includes not only farmers but also entrepreneurs responsible for inputs and services, the food industry (processing) and trade [2, 6, 31]. Since Poland joined the structures of the European Union, the agri-food sector has become a key sector for the Polish economy and the agri-food sector has become a leader in Polish trade [21, 30, 34]. The development of agri-food processing was indicated as a priority action in the "Programme for Development of Main Agricultural Markets in Poland 2016–2020".

Modern agricultural production is referred to as Agriculture 4.0. It uses many innovative technologies [11, 15, 35]. These solutions include, among others autonomous vehicles, innovative agricultural machinery. The structures of modern agricultural tractors and machines are increasingly equipped with modern automation and electronics systems [9, 13, 20].

An example of a modern and very efficient device is an electronic weighing-packing machine [7, 10, 17]. It works by weighing a given amount of the product and pouring it into a substituted bag. It is possible to combine the scale with other automatic packaging machines. Tapes of this type of equipment used must have a food certificate and be suitable for contact with food. A novelty in this type of machine is the use of a touch panel to control the device. The scale is characterized by high performance and high accuracy during weighing.

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OVERVIEW OF SOLUTIONS AVAILABLE ON THE MARKET

In the vegetable industry, two types of weighing-packing machines are most often used: tape and drawer. The drawer weighing-packing machines are used when a high capacity of 10-15 tons per hour is required. This type of scales is also characterized by greater accuracy, which is obtained through a special algorithm that controls the weighing process. Typically, the goods transported by the conveyor go to the buffer chamber where they are spread over the entire width of the weighing area. Then, in each weighing cycle, the goods are transferred to the appropriate drawer chamber through vibrating chutes or, less frequently, belt conveyors. The amount of product reaching there is specified within a specific value range. The computer which controls the process and knows the value of each individual drawer chamber then selects the mass and the number of chambers with the sum of masses closest to the set mass. This is done on the basis of an algorithm based on a mathematical variance. After the selected chambers are opened, the product goes to the transverse collecting conveyor and is transported to a raschel bag or foil packing machine. After each cycle, the chambers are replenished, which is not limited to replenishing the empty ones, but also, if necessary, the product is poured into the chambers where the weight value is not within the specified range. This need arises because the cycle of filling the chambers designed to speed up the operation of the machine is limited to a specific time. The greater number of drawers translates into shorter filling time, at the expense of a greater selection of masses among all the chambers. It may even so happen that the algorithm selects the mass from 9 out of 10 chambers. The margin of error in weighing such goods is approx. 150 grams, and the minimum weighing value is approx. 250 grams [18], so it is possible to weigh small portions of goods (Fig. 1).

Fig. 1. Drawer weighing machine by Manter.
Rys. 1. Wagoworkownica szufladkowa firmy Manter.
Saurce: Own study based on [18]
Źródło: Opracowanie własne na podstawie [18]

Belt weighing machines, used more often in smaller production, are characterized by a less advanced design and are a great deal cheaper. They are used by agricultural producers who do not require higher capacity than 3 tons per hour and the overall production will be balanced by lower accuracy – about 300 grams and the minimum value of the weighed mass within 1-5 kg, depending on the solution [4, 19]. Belt scales are divided into single-belt or double-belt types.

Single-belt weighing-packing machines are used for vegetables whose shape hinders the free flow of the product, e.g. carrots or parsley. Another decisive factor that determines the choice of such a scale is its simplicity of construction, and thus also its price. Such a weighing-packing machine is built of a single conveyor with alternately set drivers. The weighing basket is filled by moving the belt, slowing it down appropriately, and then stopping it. An example of such scales is shown in Figure 2.

Fig. 2. Single-belt weighing-packing machine by Sorpac.
Rys. 2. Wagoworkownica jednotaśmowa firmy Sorpac.
Saurce: Own study based on [19]
Źródło: Opracowanie własne na podstawie [19]

Double-belt scales are more accurate and are used for e.g. oval-shaped vegetables. In addition to the main belt, they have an additional narrow weighing belt. The work cycle of such scales begins with the movement of both belts and a proportional slowing down, depending on the weight of the weighing basket being filled. In the final stage of filling, the main belt stops and the narrow weighing belt dispenses the remainder of the product [4]. A computer is responsible for controlling the work cycle, whose algorithm is responsible for the proper regulation of the movement of the belts (Fig. 3).

Fig. 3. Double-belt weighing-packing machine by Biljsma Hercules.
Rys. 3. Wagoworkownica dwutaśmowa firmy Biljsma Hercules.
Saurce: Own study based on [4]
Źródło: Opracowanie własne na podstawie [4]

Differences in the construction of such scales between manufacturers are small. They mainly differ in the way of hanging the weighing basket: the basket is suspended from the top on 2 strain gauge beams; the basket with a lower hook on one central beam; the basket is suspended from the top on a single beam attached to the basket handle.

Another significant difference in construction is the shape of the loading hopper – the baskets are connected together with the bulkhead side of the conveyor or are bolted separately to the conveyor structure.

Manufacturers currently focus mainly on improving the control of such devices. A simple solution is to use analogue logic gates based on contactors, but such a solution gives little opportunity to adapt the operation to real conditions. Better results are achieved with the use of PLC controllers, often connected with the HMI panel and a graphic menu interface [4, 19]. Although the producers provide ready-made operating modes for particular types of vegetables, the operator can additionally adjust the appropriate parameters at their own discretion.

THE AIM OF THE PAPER

The purpose of the design of the automated two-belt weighing-packing machine for vegetables is to show the possibilities of cheap microprocessor solutions from the Arduino family. They are much cheaper than the automation solutions based on PLC controllers which currently dominate the industry [27]. The standard PLC controllers, despite being adapted to work in industrial automation, are outdated solutions. The implementation of control systems based on the programming languages available in them, i.e. most frequently with the use of ladder logic, is strenuous with more advanced systems. The C++ language is a much more modern universal language. It offers the possibility of structured as well as object-oriented programming, thanks to which the program implementation with the use of appropriate design patterns is much easier, and the code is characterized by high transparency, even with complex systems [5]. Another advantage of Arduino is the fact that it is currently the most popular open-source microprocessor solution in the world, so there is a large number of libraries for facilitating the operation of peripheral systems (LCD displays, converters, stepper motor drivers), as well as a publicly available database of projects and courses and a user-friendly, free environment [1].

DESCRIPTION OF THE MECHANICAL PART

The main element of the automated double-belt weighing-packing machine (Fig. 4) is a double-belt conveyor (1) based on a welded frame (2) with adjustable legs in order that it can be levelled on any surface. The conveyor consists of two outer sides divided by a partition in the proportion of 400 mm to 120 mm. These dimensions are also the width of the belts made of PVC. There are 60 mm high drivers glued to the belts, so that the product can be transported upwards at an angle of 45 degrees. The product is poured into the double-belt conveyor through the loading hopper (3); it has been designed in such a way that the product can go both from the pallet box tipper and from all machines preceding the technological line whose final stage is the weighing. The belts are driven by angular geared motors (4 and 5) directly attached to the driving drums of the conveyor. The rotation of the motor around the shaft axis was blocked by a torque arm bolted to the gearbox and the side of the conveyor. The weighing basket (7) was suspended on two strain gauge packages (6). Each strain gauge package consists of two strain gauge beams with a maximum weighing range of 20 kg each. The beams were permanently bolted to the upper plate, while the lower closing plate was divided into two parts so that both beams could operate independently. The design assumption was that the compactly closed packages were resistant to working conditions and could constitute one uniform spare part, the replacement of which would be limited to switching the cable and screwing the new part. The weighing basket is covered with an adhesive anti-deflection sponge resistant to dirt and humid working conditions. The product is poured out by opening the rotating flap. The movement and closing state of the flap are forced by pneumatic actuators. After opening the flap, the product goes to the discharge channel (8), at the end of which a sheet metal is bent in a way that allows the operator to hook the bag. The channel was made in an open system so that the flowing product does not create blockages and the operator can control the quality of the product in real time.

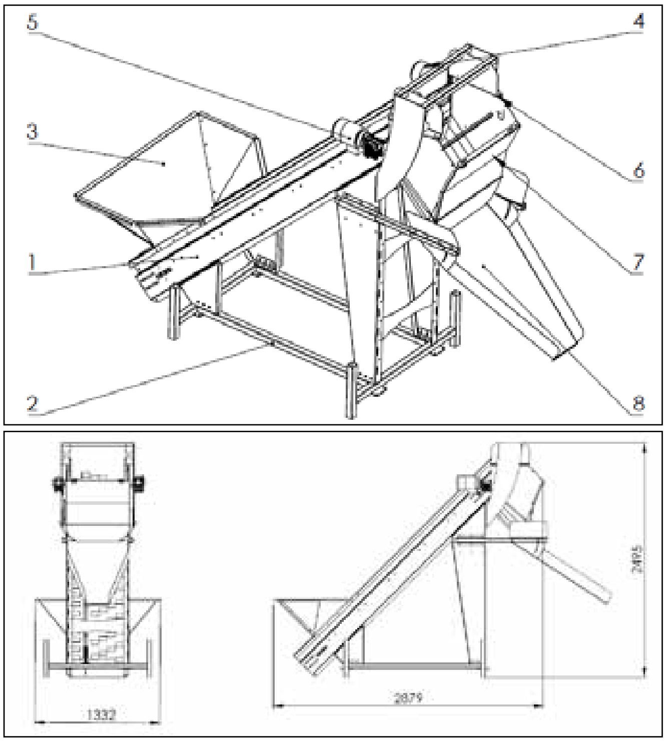

Fig. 4. Construction of the designed weighing-packing machine: 1 – double belt conveyor; 2 – welded frame; 3 – loading hopper; 4 – angle gear motor #1; 5 – angle gear motor #2; 6 – strain gauge packages; 7 – weighing basket; 8 – discharge channel.

Rys. 4. Konstrukcja zaprojektowanej wagoworkownicy: 1 – przenośnik dwutaśmowy; 2 – rama spawana; 3 – kosz zasypowy; 4 – motoreduktor kątowy 1; 5 – motoreduktor kątowy 2; 6 – pakiety tensometryczne; 7 – kosz ważący; 8 – kanał zrzutowy.

Saurce: Own study

Źródło: Opracowanie własne

DESCRIPTION OF THE CONTROL SYSTEM

The presented mechatronic weighing machine is based on the Arduino Mega 2560 R3 module with the AVR ATmega2560 microcontroller with 256 kB Flash memory, 8 kB RAM, 54 digital outputs/inputs (15 of them can transmit PWM signal), 16 analog inputs and popular communication interfaces [1]. Arduino works in the 5V standard and is sensitive to external interference from AC devices, especially the inverter, so it is important to isolate typically electronic circuits operating at 5V. After connecting to a 3-phase source, the power supply system is divided into 3 sections: 400V 3-phase AC; 24V DC generated with an industrial power supply; 5V DC generated with an industrial power supply.

The 400V 3-phase circuit is connected to the inverter only. 24V contactors (motor 1 contactor and motor 2 contactor) are connected in parallel to the output of the 3-phase inverter. Their task will be to start the motors: Motor 1 of the small belt with a power of 0.37kW and Motor 2 of the large belt with a power of 0.37kW.

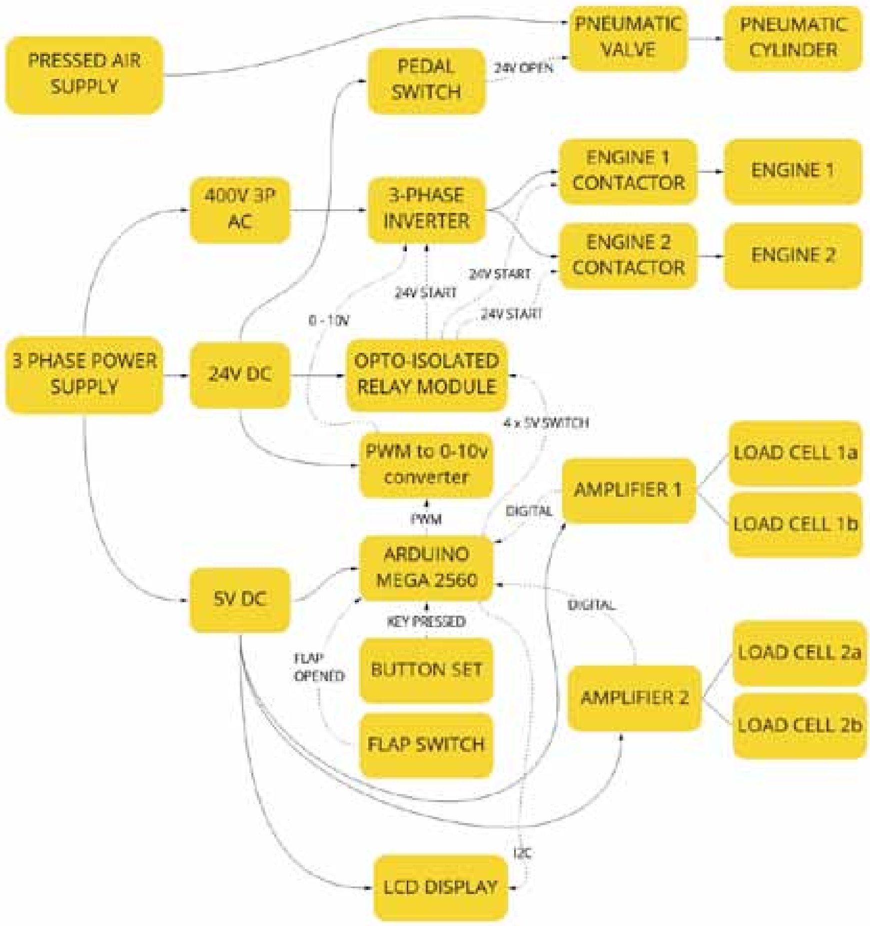

Fig. 5. Schematic model of the weighing machine control system.
Rys. 5. Model ideowy systemu sterowania wagoworkownicą.
Saurce: Own study
Źródło: Opracowanie własne

The 24V DC circuit is used to control the actuating devices. The circuit is isolated from the 5V voltage. It supplies power to the pedal switch. The pedal switch is connected directly to the pneumatic solenoid valve which, when opened, supplies pressurized air to the pneumatic actuators responsible for opening the loading hopper flap. No voltage on the solenoid valve causes the loading hopper flap to close. Moreover, 24V is the voltage that is switched on by an opto-isolated relay module that activates the contactors of motors 1 and 2, starts the inverter with a 24V START signal and powers the PWM (Pulse-Width-Modulation) signal converter at between 0 and 10V.

The 5V DC circuit is responsible for powering the electronics (Arduino module, LCD display, strain gauge beam amplifier #1, strain gauge beam amplifier #2).

Arduino receives the following input signals: 5 bit signals from the set of buttons on the control panel; 1 bit signal from the flap opening sensor; 2 x digital signal from the strain gauge amplifiers, which take measurements on 2 parallel connected strain gauge beams and send out the measurement result in digital form [29].

Arduino sends the following signals: 4 x bit signal for opto-isolated relay module (inverter start signal, motor #1 contactor switch-on signal, motor #2 contactor switch-on signal, warning light switch-on signal); 1 x PWM signal to the PWM converter – 0 to 10V, used to control the rotational speed of the inverter; 1 x I^2C serial signal for the LCD display.

After proper connection, thus configured infrastructure permits the implementation of software controlling the machine operation (Fig. 5).

INSTALLATION OF ELECTRICAL AND ELECTRONIC COMPONENTS

In the prototype, it was decided to separate the electrical part working with 400V 3-phase AC and the electronic part powered by 5V DC. Two separate units were used for this purpose.

Transfer box #1 (Fig. 6A) includes a connection to a 400V 3-phase mains supply and: Main power switch; Residual current protection; Overcurrent protection; 24V and 5V DC power supplies; Inverter; Contactors for starting motors controlled with 24V voltage; 24V connection to the pedal of the pneumatic solenoid valve of the flap opening.

Transfer box #2 (Fig. 6B) contains all the control electronics and the user's panel. It includes respectively: The Arduino Mega 2560 R3 module embedded in the housing with connectors for easy cable connection; PWM signal converter to 0-10V; Module of 4 relays controlling the 24V power supply for: inverter start, motor contactor #1, motor contactor #2, warning light; Set of switches for setting the machine; LCD display; Connection to strain gauges #1 and #2; Connection to the flap opening limit switch.

Transfer case #2 receives from case #1: 5V DC; 24V DC; Inverter start signal 24V; 24V signal to motor contactor # 1; 24V signal to motor contactor 2; 0-10V signal for controlling the frequency of the motor supply voltage, i.e. their rotational speed.

SOFTWARE IMPLEMENTATION

The full software for setting operating parameters and the weighing process itself takes approx. 500 lines of code. The program uses the following libraries:

- EEPROM – internal library used to write and read data from EEPROM semiconductor non-volatile memory, which is equipped with Arduino Mega 2560 R3;
- Wire – internal library used for communication via the I²C serial bus;
- LiquidCrystal_I2C – external library used to operate the LCD screen with a converter based on the PCF8574 integrated circuit via I²C;
- HX711 – a library that supports the 24-bit digital amplifier for strain gauge beams.

The program can be divided into 4 sections:

- Global declaration and definition of constants (including input and output pins, coefficients for weight calculation, start delay of engines and their maximum speed) and variables (initial machine settings, working variables determining the state of the weighing process). Thanks to this approach, the software is easily maintainable, it is adapted to a quick change of outputs, inputs and operating parameters, and the code is clearer;
- The setup() function – a function that is run at startup – the output and input pins are defined with predefined constants, and the LCD screen and weighing systems are initialized. Thanks to proper parameterization;
- The main loop() – the actual loop is continuously executed while the program is running. It is divided into 2 main blocks: the block of settings and menu operation by buttons and the block responsible for the weighing process;
- Auxiliary functions section – Most of the repetitive code has been wrapped in helper functions and used in the main loop (Fig. 7 and Fig. 8). On account of that, the code is shorter, the main loop contains only the proper logic, and the change of the implementation of individual methods is easily modifiable.

A B

Fig. 6. Transfer case: A – Transfer case no. 1; B – Transfer case no. 2.
Rys. 6. Skrzynia rozdzielcza: A – Skrzynia rozdzielcza nr 1; B – Skrzynia rozdzielcza nr 2.
Saurce: Own study
Źródło: Opracowanie własne

```
double GetWeight() {
   double w1 = scale.get_units();
   double w2 = scale2.get_units();

   double weight = w1 + w2;
   if (abs(weight - currentWeight) < 5.0
failedWeightsCounter > 2) {

currentWeight = weight;

failedWeightsCounter = 0;
   }
   else {

failedWeightsCounter++;
   }

   return currentWeight;
}
```

Fig. 7. Reading of the weight, filtering the interference in the digital signal received from the amplifier, used in the loop.
Rys. 7. Odczyt wagi filtrujący zakłócenia w sygnale cyfrowym otrzymywanym ze wzmacniacza używany w pętli.
Saurce: Own study
Źródło: Opracowanie własne

The process control itself of the proper weighing has been developed empirically on the basis of time and accuracy tests for various weighing process runs (Table 1). The weighing process has been divided into 6 steps, in which the speed of the motors and the moment of disconnecting the large belt motor are selected on the basis of the missing mass. Empirically selected settings of the motor speed and the step switching thresholds ensure maximum efficiency without increasing the

```
   bool PressedButton1() {
      if (digitalRead(button1) == LOW) {

   if ((button1Timer++ % buttonsMultiplier == 0

   && button1Timer > buttonEdgeTime

   )

   || button1Timer == 1) {

   return true;

   }
      }
      else {

   button1Timer = 0;
      }
      return false;
   }

   bool PressedButton1Long() {
      if   (button1Timer   >   buttonEdgeTimeLong)
return true;
      return false;
   }
```

Fig. 8. Example of methods that support short and long-term button presses, adapted to loop operation.

Rys. 8. Przykład metod obsługujących krótkotrwałe i długotrwałe naciśnięcie przycisku przystosowane do działania w pętli.

Saurce: Own study

Źródło: Opracowanie własne

deviations from the set mass. For a mass difference of less than 1.2 kg, the motor of the larger belt is completely disengaged.

Table 1. Steps of the weighing process depending on the difference between the given mass and the actual mass

Tabela 1. Kroki procesu ważenia uzależnione od różnicy masy zadanej i aktualnej masy

Step number	Weight difference (kg)	% of maximum speed	Bigger tape engine	Smaller tape engine
1	>7	100	On	On
2	>4	75	On	On
3	>3	50	On	On
4	>2	25	On	On
5	>1.2	25	Off	On
6	> 0.2	10	Off	On

Saurce: Own study

Źródło: Opracowanie własne

MEASUREMENTS OF PERFORMANCE AND EFFICIENCY

In order to verify the effectiveness of the designed prototype, 3 series of measurements were performed for the process of weighing potatoes. A few weighing cycles were performed and then the mass of potatoes that was poured was recorded. Measurements were made for standard sizes of potato packaging: 2, 5 and 10 kg. The measurement results are as follows (Fig. 9), (Table 2).

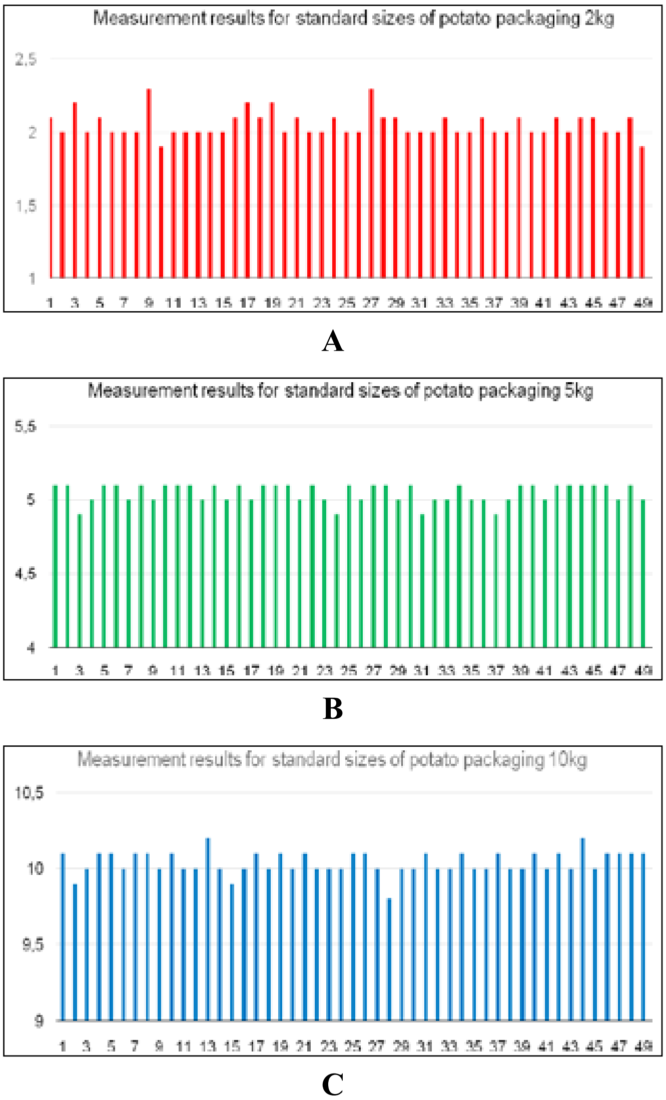

Fig. 9. Measurement results: A – Measurement results for standard sizes of potato packaging 2 kg; B – Measurement results for standard sizes of potato packaging 5 kg; C – Measurement results for standard sizes of potato packaging 10 kg.

Rys. 9. Wyniki pomiarów: A – Wyniki pomiarów dla standardowych rozmiarów opakowań do ziemniaków 2 kg; B – Wyniki pomiarów dla standardowych rozmiarów opakowań do ziemniaków 5 kg; C – Wyniki pomiarów dla standardowych rozmiarów opakowań do ziemniaków 10 kg.

Saurce: Own study

Źródło: Opracowanie własne

Table 2. Mean and standard deviation of the measurements

Tabela 2. Średnia i odchylenie standardowe pomiarów

Parameter	2 kg	5 kg	10 kg
Std. Deviation	0,079	0,065	0,073
Average	2,050	5,048	10,042

Saurce: Own study

Źródło: Opracowanie własne

SUMMARY

Three series for the given masses: 2 kg, 5 kg and 10 kg made it possible to verify the suitability of the prototype made. Slight deviations from the set mass were observed. The recorded standard deviation and the average deviation from the set weight did not exceed the weight of two potatoes. The highest standard deviation (0.08 kg) was observed at the value of 2 kg. Also, this series of measurements was characterized by the highest deviation of the mean from the set mass (0.05 kg). This is most likely due to a certain inertia of the engines observed at their start-up, as a result of which the deceleration of the engines in the last stage of weighing occurs with a certain delay. The most effective portioning took place when potatoes were weighed in 5 kg portions. The deviation from the mean was 0.048 kg and the standard deviation was 0.065 kg. This is probably due to the lower starting rotational speed of the engines, so the deceleration itself occured faster.

For all the three series of measurements, the results are fully validated, which confirms the effectiveness of the solution. The proposed design of an automated weighing and packing machine can be successively used as a weighing element of a potato line in production on an industrial scale. The machine's capacity for 5 kg bags is estimated at 2 tons per hour.

PODSUMOWANIE

Trzy serie dla zadanych mas: 2 kg, 5 kg oraz 10 kg pozwoliły zweryfikować przydatność wykonanego prototypu. Zaobserwowano niewielkie odchylenia od zadanej masy. Zarejestrowane odchylenie standardowe i odchyłka średniej od zadanej masy nie przekroczyły wagi dwóch ziemniaków. Największe odchylenie standardowe (0,08 kg) zaobserwowano przy wartości 2 kg. Również tę serię pomiarów cechowała najwyższa odchyłka średniej od zadanej masy (0,05 kg). Wynika to najprawdopodobniej z pewnej bezwładności silników zaobserwowanej przy ich starcie, w wyniku której samo zwalnianie silników w ostatnim etapie naważania następuje z pewnym opóźnieniem. Najskuteczniejsze porcjowanie miało miejsce dla przypadku ważenia ziemniaków w porcje 5kg.

Odchyłka od średniej wyniosła 0,048kg, a odchylenie standardowe 0,065 kg. Wynika to prawdopodobnie z niższej startowej prędkości obrotowej silników, a więc samo spowalnianie ich następowało szybciej.

Dla wszystkich trzech serii pomiarów wyniki są w pełni akceptowalne co potwierdza skuteczność rozwiązania. Proponowana konstrukcja automatycznej wagoworkownicy może być sukcesywnie używana jako element ważący linii do ziemniaków w produkcji na skalę przemysłową. Wydajność maszyny dla worków 5 kg szacuje się na poziomie 2 ton na godzinę.

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