AGRICULTURAL UNIVERSITY PLOVDIV
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Stepless adjustment of the sowing rate for the Saxonia A200 row drill

A B S T R A C T

of a dissertation for the award of a educational and scientific degree "DOCTOR"
scientific specialty "Mechanization and electrification of crop production"

SUPERVISOR:
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Plovdiv, 2024

The research was conducted in the period 2020-2023 in the laboratories of the Department of Agricultural Mechanization at AU-Plovdiv and agricultural holdings in the area of Pazardzhik.

The dissertation is written on 114 pages and contains 16 tables, 22 figures, 51 formulas. The cited literature includes 112 sources, of which 87 are in Cyrillic and 25 are in Latin.

The dissertation work has been discussed and directed for defense by the departmental council of the department "Mechanization of agriculture" at the Faculty of Viti- and Horticulture at the Agricultural University - Plovdiv

The defense of the dissertation will take place on ……………. from 11:30 a.m. in the 2nd hall of the Department of Agricultural Mechanization at AU - Plovdiv in front of a Specialized Scientific Jury, approved by Rector's Order No. RD-16-366 dated 12.03.2024, composed of::

Internal Members:
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The defense materials are available to those interested in the library of the Agrarian University - Plovdiv, 12 Mendeleev Blvd.

I. INTRODUCTION

The sowing rate is the optimal number of seeds to be sown per unit area. Sowing depth also affects productivity. If the seeds are sown at a shallower depth, the plants develop slowly, especially at the beginning. The fact is that the upper layer of the soil dries out, the root system develops more slowly, the roots become weak and the plants are held in the soil worse. When seed depth is uneven, then plant growth and development is also uneven. As a result, plants with taller stems will interfere with those that are weaker and shorter. And this will lead to a decrease in yield.

Sowing should be done in the soil that is at the optimum temperature and humidity and during the best agrotechnical term, considering that the planter and the tractor work inefficiently in waterlogged soils.

For the object of the research, it is appropriate to select one of the most widespread technical means in our country for ensuring the sowing process with a toothed (pin) sowing device, namely the Saxony A200 row seeder.

In accordance with this, the essential characteristics of seeds, technique and the process of sowing seeds are taken as the subject of the study.

This can be achieved through appropriate theoretical-experimental research, applying the methods of planning the experiment, variation, regression and dispersion analyses.

Units with conditions close to our agrarian production, equipped with the necessary equipment and measuring tools - in this case the scientific laboratories of the Agricultural University - Plovdiv, were selected as the place of the study.

II. AIM AND TASKS

The aim of the research is to develop a system for stepless regulation of the sowing rate in planters for crops with a "fused surface".

<u>*Tasks of the research:*</u>

1. Determination of the theoretical bases for stepless regulation and maintenance of the sowing rate for wheat under variable working conditions;
2. Determining the necessary power to drive the sowing devices of the Saxonia A200 seeder;
3. Determination of the sown quantity of wheat seeds for one revolution of a toothed (pin) sowing device;
4. Determination of the functional relationship between the transmission number in the transmission mechanism, the density of seeds and the quantity of sown seeds;
5. Development of a version of an electronic system for managing the sowing rate for the Saxonia A200 row drill;
6. Determining the reduced operating costs depending on the transmission mechanism (mechanical or electronic) used in the row drill when sowing cereals with a "fused surface".

III. GENERAL RESEARCH METHODOLOGY

III.1. Determining the required power to drive the sowing devices of the Saxonia A200 planter

The sowing devices are driven by the support wheel of the seed drill, through a system of chain and toothed gears. The last step in the transmission system is a chain gear.

Power is known to be the product of torque and angular velocity.

The angular velocity of the seed drill shaft can be represented as the product of the angular velocity of the idler wheel and the gear ratio in the transmission mechanism of the planter. The angular speed of the idler wheel is determined using the peripheral speed formula (the operating speed of the planter).

$$V_p = \omega . R \qquad (1)$$

According to some authors, when sowing cereals with a "fused" surface, the recommended working speed is from 7 to 12 km/h.

When the seeding rate of winter wheat is increased, the uniformity of seed application is reduced due to the change in the resistance of the boot. At higher speeds and especially when an obstacle is encountered, the boots rise and the seeds are spread over the soil surface or introduced into different soil layers.

Trials were conducted for direct seeding at speeds of 8 to 16 km/h with different boots. The results of this field experiment highlight the problems with no-till technologies and provide an attractive solution for higher operating speeds in seeding. Further studies are needed to optimize the design parameters of the boots.

It has been proven that in no-till sowing of cereal crops there is an unprecedented opportunity to increase working speeds by 50% without affecting emergence or yields. This increase in operating speed can improve seeding practices in the industry by:

(1) timeliness of sowing, therefore increasing grain yield potential,

(2) reducing the total sowing time for a season or reducing the required working time per day for the farmer;

(3) potential to reduce machine width to minimize investment costs while maintaining a similar operating speed.

In the present work, a speed of 12 km/h (3.33 m/s) is used.

The radius of the support wheel of the Saxonia A200 planter is 0.58 m.

Solving equation 1 with respect to the angular velocity gives

$$\omega = \frac{V_p}{R} \qquad (2)$$

The gear ratio is represented as the product of the gear ratios of each pinion and chain gear in the transmission mechanism of the row drill. The transmission mechanism of the Saxonia A200 planter includes 3 chain gears and one multi-stage gear reducer.

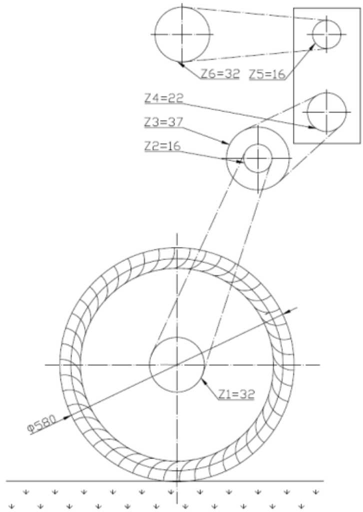

Figure 1 Transmission mechanism of a Saxonia A200 planter

The gear ratio of chain gears is defined as dividing the number of teeth on the driven by the number of teeth on the driving gear.

$$i_{\text{в}i}=\frac{z_2}{z_1} \qquad (3)$$

Due to the lack of technical documentation for the seeder, the transmission ratio of the reducer is determined as a fraction of the number of revolutions of the input shaft for 1 revolution of its output shaft.

$$i_{\text{р}}=\frac{n_{\text{вх}}}{n_{\text{из}}} \qquad (4)$$

The overall gear ratio is the product of the gear ratios of each gear

$$i_{\text{пм}}=i_{\text{в}1}.i_{\text{в}2}.i_{\text{р}}.i_{\text{в}3} \qquad (5)$$

To rotate drive shafts, it is necessary to apply a torque equal and opposite to the resistance torque generated by the frictional forces in the bearing bodies and between the drills and the seeds. To determine this moment, the chain is removed, and then the gear wheel is dismantled from the drive shaft of the seeders. A 0.615 m long arm is installed in its place. At the end of the arm, weights are placed one after the other until the shaft rotates. The torque is composed of 2 components - the first is the moment obtained by the action of the weights, and the second - the moment created by the mass of the arm. The mass of the arm can be thought of as a uniformly distributed load. Her moment is the product of her and half the shoulder length.

The torque is determined using the following figure 2.

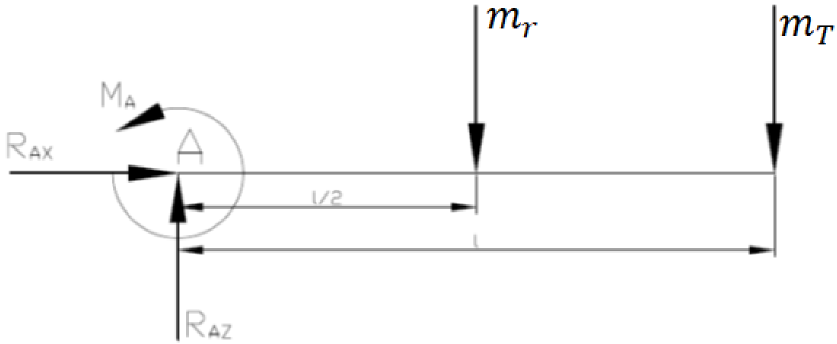

Figure 2

According to the above the torque is:

$$M = 9{,}81.\left(m_r.\frac{l_2}{2} + m_T.l_2\right) \quad (6)$$

The number of repetitions when measuring the quantities: weight of the arm, weight of the weights and transmission ratio in the reducer is determined at the level of significance α=0.05 and relative error δ=5% according to the recommendations of the authors.

The obtained results of the measurements for each value are averaged and these values are substituted in the formulas listed above to obtain the required power.

III.2. Determination of the functional relationship between seed density and the amount sown (sown volume) for one revolution of a toothed (pin) seed drill

The necessary experiments are carried out in laboratory conditions, in the "Agricultural Mechanization" department at AU-Plovdiv, with a Saxonia 200A planter. The slide of the observed seeding device is set to position - middle, the movable bottom - to position 1.

The drive of the seeders is provided by a transmission system consisting of 3 chain gears and a gear reducer allowing 72 transmission ratios. The drive from the right travel wheel through the transmission system is fed to the seed apparatus.

In the present study, 6 of the possible gears in the gear reducer are randomly selected.

A crank is installed on the guide wheel of the second chain gear. For each of the selected gears in the gear reducer, the transmission ratio in the transmission system is determined by taking into account the number of revolutions of the crank, during which the shaft of the seeders makes 1 complete rotation.

Before each trial, the seed box for seeds is filled. 10 revolutions are made with the crank in order to remove the seeds located in the sowing device. Then 42 revolutions are made with the crank. The seeds sensed by the monitored sowing device are collected and weighed on the scale.

The number of replicates was determined at a significance level α=0.05 and a relative error δ=5% according to the authors' recommendations, and the obtained results were averaged.

The data obtained from the measurements are reflected in tables.

The amount of seeds sown in 1 revolution of the seeder y is determined by dividing the product of the amount of seeds sown in 42 revolutions of the crank x and the revolutions of the crank required for 1 revolution of the seeder n_1ca by 42:

$$y = \frac{x.n_{1ca}}{42} \tag{7}$$

Presented in unfolded form, the amount of seeds sown for 1 turn is:

$$y = \rho.V_0 \tag{8}$$

The volume sown in 1 revolution of the sowing device is obtained by dividing the amount of seeds sown by the density of the sown material:

$$V_o = \frac{y}{\rho} \tag{9}$$

III.3. Determination of the functional relationship between the gear ratio in the transmission mechanism, seed density and the amount of seed sown

To solve this task, an experiment is being conducted according to plan B2 in the teaching laboratories of the "Agricultural Mechanization" department at AU-Plovdiv. The independent variables (factors) in the present cases are: the density of the seeded material and the transmission ratio (rotation speed of the sowing device).

Each of the two factors varies at three levels.

For the density, seed materials with a bulk weight of 250, 537 and 825 kg/m^3 were selected.

Regarding the other factor, gear ratio, it is determined as follows: In the review of reference literature, no information was found on what the gear ratio is for the various gears in the gearbox. For this reason, attempts are being made to establish them. The gearbox has input and output shafts. A chain gear is attached to each of them. The highest part of each gear is marked with a marker and a mark is placed against them on the wall of the reducer with the marker. In the entire transmission system, only this gear ratio can be changed, and that in a stepwise manner.

There are 3 handles on the front wall of the reducer, with which the different gears can be switched, and from there different transmission ratios can be realized. The lowest gear (highest gear ratio) is 111 and the highest gear is 634. The third (middle) point in the experiment plan regarding the gear ratio remains to be specified. It must be equidistant from the two above.

For each gear, the reducer is turned with the crank, taking into account the revolutions of the input shaft, necessary for 1 revolution of the output shaft. The number of repetitions is determined at a significance level α=0.05 and a relative error δ=5% according to the recommendations of the authors. The results obtained from each experiment are averaged. The obtained numbers determine the transmission ratio in the reducer for each of the gears, according to formula 4.

Before each trial, a seed box is filled. 20 revolutions are made with the crank in order to remove the seeds in the seeding device from the previous experiment and only then 42 revolutions are made, which corresponds to 1/10 of the sowing rate. The sown seeds are collected and weighed on the scale.

To facilitate the experiment, first work with one culture (density) and determine the amount of seeds sown at the different gears, then - with the second culture and finally - with the third.

For each point of the experimental plan, the operation is repeated 3 times. The obtained data are averaged and factor and regression analyzes are carried out with them.

With the factor analysis, the influence of each of the factors on the change in the sown amount is determined. The regression analysis specifies the functional relationship between the factors and the observed indicator. The resulting regression equation is displayed graphically with a regression surface and equal response lines using the Statistika v.7 software product.

III.4. Determining the reduced operating costs depending on the transmission mechanism used in the row drill when sowing cereals with a "fused surface".

Each machine-tractor unit (MTU) can be represented as composed of an energy device (tractor) and a working machine (row drill). The row seeder can be built with a variator, with a reduction gear or with an electro-mechanical (mechatronic) drive of the seeders. In all three variants, the tractor has the same price. As a result, the difference in the price of the MTU is determined solely by the price of the transmission mechanism built into the row drill.

MF4708M tractor and Saxonia A200 analogue seeder, with a working width of 3 m, are used as the basis in this work. The driving of the seeders is carried out by the running wheel by means of a variator. In the second option, it is possible to replace the variator with a 32-speed gear reducer. In the third variant, the mechatronic system for driving the seeders includes a controller, a frequency regulator, a tachometer and a DC motor.

The price of the row drill and variator in the first option is taken by the distributor. In the second and third options, the price of the variator is deducted from the price of the seed drill. To this value is added the cost of the gear reducer/separate elements making up the "electronic transmission mechanism", thus obtaining the cost of the planter in these two variants.

The price of the entire MTU is formed as a sum of the price of the tractor and the price of the planter.

It has been established that the optimal agrotechnical term for sowing wheat and barley is from 20.IX. until 15.XI. Extending the sowing period leads to a decrease in yields. As a calendar duration, the optimal agrotechnical term is within 25 days, during which the MTA machine-tractor unit is used. In case of unfavorable agrometeorological indicators, this term can be extended to 40-60 days.

The main economic indicator for evaluating the three options is reduced operating costs. This is the relationship between the operating costs of each sowing unit and its productivity.

The operating costs include: depreciation deductions, deductions for current repair and maintenance, storage costs, salary fund (FRZ), fuel and lubricants (GSM), tire replacement costs, etc. The goal is to minimize these costs. Mathematically, the problem is written in the following form:

$$EP \rightarrow min \qquad (10)$$

where:

$$EP=ФРЗ+АО+ТРП+ГСМ+РГ \qquad (11)$$

ФРЗ - WAGE FUND.

Fund wages of the tractor driver and auxiliary workers are taken from the tariff rates for work in an eight and a half hour work day. In doing so, it is necessary to take into account seniority allowances, class allowances, holiday allowances and social insurance. According to the Ordinance on the categorization of labor upon retirement (NCTP), the work of mechanics and auxiliary workers in agriculture is of category III. The total amount of insurance that the employer is obliged to pay for this work is 18.52% of the insurance income,

In order to establish the FRZ for the machine operator (tractor operator) and the auxiliary worker, a survey is conducted in farms of different sizes in the Pazardzhik region to specify their pay for servicing the sowing unit.

FRZ is calculated according to dependency 12.

$$ФРЗ=(С_м + С_{ср}).(1 + ДОО).Д_н \qquad (12)$$

GSM - Costs for fuel and lubricants

They are determined based on the consumption of the main fuel and its complex price. The complex price is the value of 1 kg of fuel and the corresponding amounts of lubricants, calculated as a percentage of the main fuel. For this purpose, the price of 1 liter of diesel fuel is specified from basic information sources based on the Internet. This price is multiplied by 1.2 to get the price of 1 kg of fuel. The resulting number is multiplied by 1.06, which accounts for the participation in the complex price of motor and transmission oils.

We will determine the complex price of the fuel according to the dependence:

$$КГ = 1{,}2.1{,}06.ЦГ \qquad (13)$$

Fuel costs are determined by knowing the volume of work, the standard fuel consumption per unit of work and the complex price of fuel. Considering the above, the costs of GMS are:

$$ГСМ = 1{,}272.ЦГ.Н_Г.U \qquad (14)$$

AO - Deductions for restoration and overhaul

These costs are determined by the book value of the machine, the standard rate of deductions for major repairs and depreciation.

For different brands of tractors and agricultural machines, the percentage of deductions for major repairs and restoration is different. It is taken from the normative documents of the farm, ministry or other authorities.

In private farms, the owners themselves can determine the period of use of a given machine, respectively, and the percentage of deductions for its overhaul and restoration. Most often, these terms are 10 years for the tractor, and 5 years for the agricultural machines. For this reason, the K_B factor for the tractor is 10, and for the agricultural machines – 20%.

Taking into account the days off and holidays in our country, it can be said that the tractor is used about 240 days a year, while the seeder is used only during the sowing campaign, which lasts about 40 days.

When determining the operating costs of the sowing unit, they will include the entire amount of deductions for depreciation and overhaul of the planter and the part of these deductions for the tractor corresponding to 40 days of work.

Following these prerequisites, the deductions for restoration and overhaul are calculated according to the following formula:

$$АО = \frac{Ц_Т.К_{ВТ}.40}{100.240} + \frac{Ц_М.К_{ВМ}}{100} \qquad (15)$$

TRP - The costs of current repairs and technical inspections

They are determined by the balance value of the machines, the percentage of deductions for current repair and maintenance. Deductions for current repair and maintenance are calculated according to the following dependence:

$$ТРП = \frac{Ц_Т.К_{ТРТ}.40}{100.240} + \frac{Ц_М.К_{ТРМ}}{100} \qquad (16)$$

What has been said above about deductions for depreciation and overhaul applies in full force when determining the costs of current repairs and maintenance. When determining them, they will include the entire volume of deductions for current repair and maintenance of the planter and the part of these deductions for the tractor corresponding to 40 days of work.

The percentage of deductions for current repair and maintenance is taken from the normative documents

RG - Tire costs

Usually, the term for tires on tractors is about 2 years. The planter works about 40 days a year. With a use and buyback period of 5 years, she will be operated for a total of 200 days, allowing her tires to not be replaced until the end of her service life.

With this in mind, the cost of replacing tires can be determined according to the following relationship:

$$РГ = \frac{Г_Ц}{2} \qquad (17)$$

Substituting formulas from 12 to 17 in relation 11 yields the following equation:

$$ЕР = (С_м + С_{ср}).(1 + ДОО).Д_Н + \frac{Ц_Т}{600}.(К_{ВТ} + К_{ТТ}) + \frac{Ц_М}{100}.(К_{ВМ} + К_{ТМ}) + \frac{Г_Ц}{2} + 1{,}272.Ц_Г.Н_Г.U \qquad (18)$$

To determine the reduced operating costs, the amount from formula 18 is divided by the product of the number of days during which the sowing unit works (40 days) and the daily productivity. In the case of the laying done in this way, the reduced operating costs are determined according to the dependence:

$$ПЕР = \frac{(С_м + С_{ср}).(1 + ДОО).Д_Н + \frac{Ц_Т}{600}.(К_{ВТ} + К_{ТТ}) + \frac{Ц_М}{100}.(К_{ВМ} + К_{ТМ}) + \frac{Г_Ц}{2} + 1,272.Ц_Г.Н_Г.U}{40.Д_Н} \qquad (19)$$

IV. THEORETICAL JUSTIFICATION OF THE STEPLESS CONTROL OF THE SOWING RATE

During operation, the sowing unit moving at speed V (km/h) cultivates an area equal to the product of the speed and the working width of the unit. The amount of seed that is sown on this area in 1 hour is the product of the area and the seeding rate. The amount of seeds sown in 1 min is defined as the quotient of the amount of seeds sown in 1 h divided by 60. In mathematical form, the above considerations are represented by the following dependencies:

processed for 1 h area $S_1 = V_p.B_p$, *dka* *(20)*

amount of seed sown in 1 h $Q_m = S_1.Q = V_p.B_p.Q$, *kg* *(21)*

amount of seed sown in 1 min $Q_{1m} = \frac{S_1.Q}{60} = \frac{V_p.B_p.Q}{60}$, *kg/min* *(22)*

In older row drills to turn the seed drills, the drive is taken from the travel wheels, passes through a chain and gear system and is transmitted to the drive shaft. As a result, their rotation speed is directly related to the forward (working) speed of the unit. The latter can be represented as a product of the angular speed of the running wheel ω and its radius R. It is known from the literature that there is a direct relationship between the angular speed of the running wheel and its rotation speed, which can be represented by the following mathematical relationships:

for the forward speed $V_p = 3{,}6.\omega.R$ *(23)*

for the angular velocity $\omega = \frac{2.\pi.n}{60}$, *rad⁻¹* *(24)*

It is possible in equation 23 to replace the value of the angular velocity with that of expression 24. A new dependence is obtained, which needs to be rationalized. After performing the necessary mathematical operations, the expression for the operating speed will take the form:

$$V = 0{,}12.\pi.n.R \qquad (25)$$

With known operating speed (can be taken from the on-board computer of the tractor in use) and radius of the running wheel, its rotational speed is obtained from expression 26:

$$n = \frac{V_p}{0.12.\pi.R.}, \ tr^{-1} \qquad (26)$$

Usually, the movement is transmitted from the running wheel to the drive shaft of the seeders by means of a transmission mechanism, the main characteristic of which is its transmission ratio i. The rotation speed of the seed drills is the product of the rotation speed of the drive wheel of the planter and the gear ratio.

$$n_{CA} = n.i = \frac{V_p}{0.12.\pi.R.}.i \qquad (27)$$

During operation, the seeders perform a rotary movement, with each pin (tooth) they grasp a certain volume of seeds and push them out of the hopper area. Let's denote the volume of seeds that 1 sowing apparatus takes out in 1 revolution by q_1. The mass of the seeds carried out in 1 revolution of the sowing apparatus is the product of their volume and their density γ, kg/m^3.

$$Q_{CA} = q_1.\gamma \text{ , } kg \qquad (28)$$

There are m number of sowing apparatus built into each planter. The total amount of seeds $Q_{1Б}$, which are removed from the hopper for one revolution of the drive shaft of the sowing apparatuses is the product of their number and the amount of seeds removed in 1 revolution of one sowing apparatus

$$Q_{1Б} = Q_{CA}.m = q_1.\gamma.m \qquad (29)$$

where m – number of sowing devices from the seeder.

The amount of seed removed from the planter hopper in 1 min is learned as the product of the rotation speed of the sowing apparatuses and the total amount of seed that is removed from the hopper in one revolution of their drive shaft. To obtain the mathematical expression of this amount of seeds, the right sides of equations (27) and (29) are used. The resulting new equation takes the form:

$$Q_{1m} = Q_{CA}.m.n_{CA} = q_1.\gamma.m.\frac{V_p}{0.12.\pi.R.}.i \qquad (30)$$

Dependency (22) gives the amount of seeds removed from the hopper of the seeder in 1 min, expressed with operating parameters of the sowing unit. In turn, dependence (30) also determines the amount of seeds removed from the planter's hopper in 1 min, but expressed with technological parameters of the seeds used and design parameters of the planter. For the planter to work correctly the right sides of the two equations must be equal. Starting from this premise, a new equality can be drawn up, which has the form:

$$\frac{(V_p.B_p.Q)}{60} = q_1.\gamma.m.\frac{V_p}{0.12.\pi.R.}.i \qquad (31)$$

The working width can be represented as a product of the number of sowing apparutuses (respectively the boots) and the size of the row spacing b. Equation (31) will not change if the operating speed and the number of sowing apparutuses are eliminated from its left and right sides. After these transformations, the equation can be solved for the seeding rate:

$$Q = \frac{159{,}236.q_1.\gamma}{b.R}.i \qquad (32)$$

b – size of the row spacing, m.

In equation (32), the row spacing at which the seeds are sown, the radius of the drive wheel, the amount of seeds that 1 sowing apparatus carries out in 1 revolution, as well as their density are constant values. From what has been said so far, it follows that the sowing rate can be considered as a function of 1 variable, namely – the transmission ratio.

The above statement applies only to seed drills, where the drive of the sowing apparatuses is carried out by the running wheel, by means of a mechanical transmission mechanism.

With independent, non-synchronous drive of the sowing apparatuses, for 1 revolution of the drive shaft, each device takes out a certain quantity $q_{об}$ [kg] of seeds from the hopper of the seeder. Since m number of sowing apparatuses are installed on each seeder, the amount of seeds carried out for 1 revolution of the drive shaft can be determined by the expression:

$$Q_{об} = q_{об}.m, \; kg/об \qquad (33)$$

Drive shaft revolutions (planters) are n_{CA} [min^{-1}]. By multiplying the amount of seeds sown in 1 revolution of the drive shaft by this speed, the amount of seeds sown in 1 min by the whole planter is obtained:

$$Q_{1m} = Q_{об}.n_{CA} \; , kg/min \qquad (34)$$

The left-hand side of formulas 22 and 33 is the same, so their right-hand sides are equal.

$$\frac{B_p.V_p.Q}{60} = Q_{об}.n_{CA} \qquad (35)$$

It is known that the working width is a product of the row spacing and the number of coulters (respectively of the sowing apparatuses)

$$B_p = m.b, \; m \qquad (36)$$

Substituting formulas 34 and 36 into formula 35 and rationalizing the new expression yields

$$b.V_p.Q = 60.q_{об}.n_{CA}, \qquad (37)$$

In the above equation, the velocity can be substituted by formula 25, from which follows

$$b.0{,}12.\pi.n.R.Q = 60.q_{об}.n_{CA} \qquad (38)$$

The expression 38 can be rationalized and after transformation will have the form

$$b.n.R.Q = 159{,}236.q_{об}.n_{CA} \qquad (39)$$

According to relation 27, the speed of rotation of the shaft of the sowing apparatuses can be represented as the product of the speed of rotation of the driving wheel and the transmission ratio. After substitution and rationalization in the above expression, we get

$$b.R.Q = 159{,}236.q_{o6}.i \qquad (40)$$

Analyzing equation 39, it can be seen that the inter-row distance and the radius of the running wheel of the row drill are constant values. The same can be said for the amount of seed that will be sown in one revolution of the sowing apparatus. This value can be obtained experimentally. The only thing that needs to be changed to realize different sowing rates for the same crop is the transmission ratio, regardless of the change in the speed of the unit.

$$i = \frac{b.R.Q}{159{,}236.q_{o6}} \qquad (41)$$

Following the logic of the above and taking into account the operating parameters of the Saxonia 200A planter formula 41 is changed

$$i = \frac{Q}{4575{,}74.q_{o6}} \qquad (42)$$

Formula 42 is the transmission function in a mechatronic system controlling and supporting the seeding process of the Saxonia 200A planter. Variables in it are the sowing rate and the quantity of seeds that are sown in 1 revolution of the sowing apparatus. It is directly dependent on their density and volume.

Relatively precisely this quantity can be determined experimentally, as will be discussed in Section V.2.

In order to switch to stepless regulation of the sowing rate, the following or a similar mechatronic block diagram must be implemented:

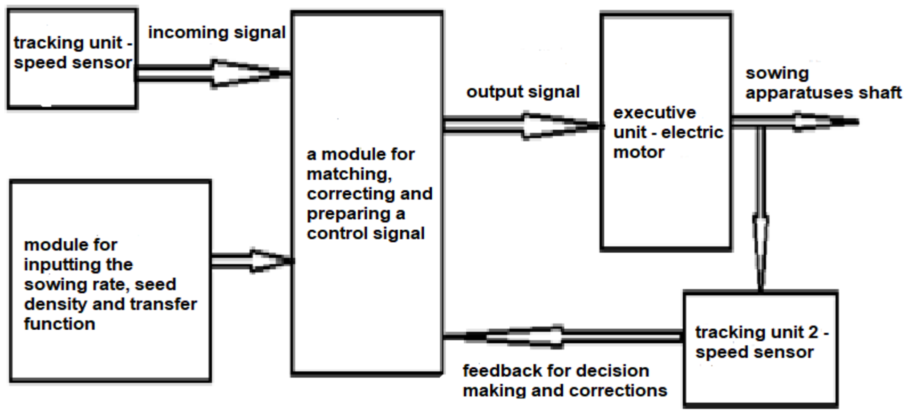

Figure 3 Block diagram of the system for stepless adjustment of the sowing rate

A variety of electrical and electronic components can be used in building the system. More specifics will be given in the next few steps.

The entire system will be powered by the tractor battery.

We will look at 2 main possibilities regarding the drive of the seeders - it can be done with a DC or AC motor.

A second important point is where the signal for the operating speed of the unit will be taken from. The first possibility is to remove this signal from the tractor computer. All modern tractors are equipped with a process control computer. The second option is to receive this signal from a special sensor mounted on the running system of the tractor or machine. The inconvenience of this is that the unit works in a rather variable environment, with a lot of vibrations, dusting, etc., which make it difficult, and in many cases even interfere with the normal operation of the sensor. For this reason, we assume that the forward speed signal is taken from the tractor's on-board computer.

IV.1. A mechatronic system with a DC motor to drive the shaft of the seed drills

Following the logic of the block diagram of Figure 3, the configuration of a mechatronic system using a DC motor will have the form presented in the following figure (Figure 4)

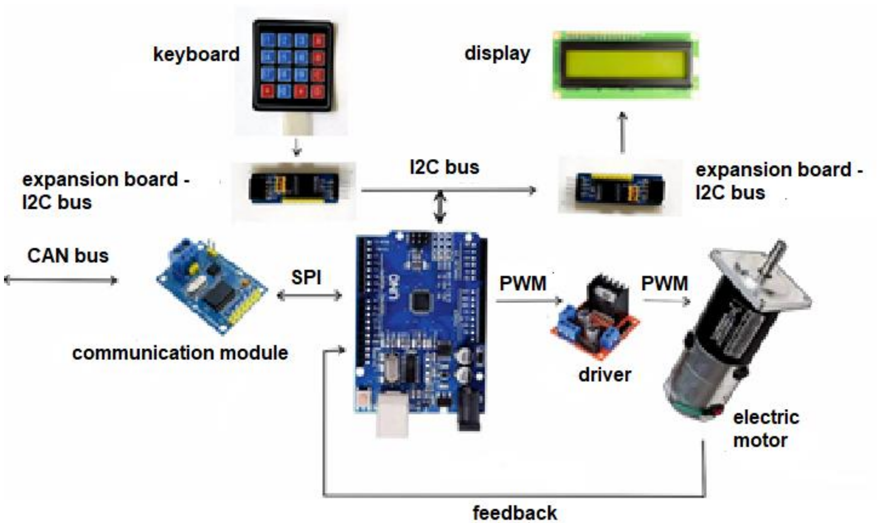

Figure 4. Device of the mechatronic system for regulating the sowing rate with a DC motor

In the present work, an operating voltage of 12 V is selected, which is provided by the tractor battery in the unit or on-board electrical system.

The information for determining the speed of the sowing unit is supplied from the tractor's on-board computer through the CAN Bus Module to the Arduino microprocessor (microcomputer) (Fig. 3). It has been shown that the development of software and hardware systems for automation and control with a mechatronic approach can be based on the Arduino microprocessor. It is a tool for developing devices that interact with the physical environment. It is an open hardware and software platform for working with physical objects. Arduino is a microcontroller board and software development environment. The platform has built-in elements for programming and integration with other devices and circuits. Arduino facilitates work with microcontrollers and provides the following advantages: low cost, cross-platform, use of additional modules for automation, control and management of various physical processes and functions.

Data on row spacing, seed rate, seed density, transmission function (gear ratio) are entered from the keyboard and fed to the microprocessor via the 12C bus. A display is also connected to the same bus, which visualizes the entered data.

Based on the input data, a control signal (PWM) is created, which, through an electronic module (Driver), commutating a larger current, drives the DC motor. The engine has a built-in encoder or tachogenerator that feeds information back to the microprocessor to make the necessary adjustments and adjustments to maintain the necessary shaft revolutions of the drills.

In physical form, the developed system for management and stepless regulation of the sowing rate is presented in Figure 5.

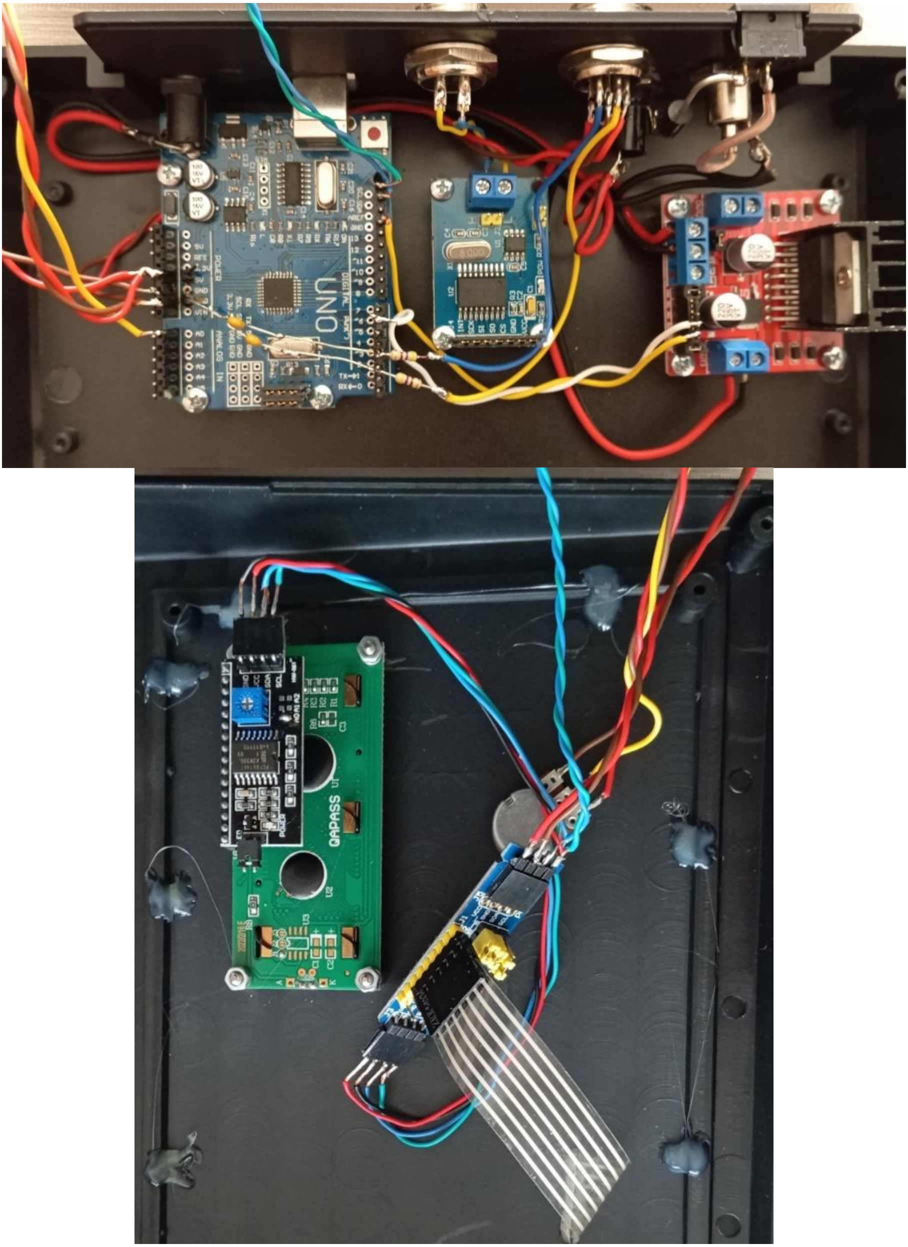

Figure 5. System for adjusting the sowing rate with a DC motor

IV.2. Mechatronic system with alternating current motor to drive the shaft of the seeders

The power supply of the mechatronic system has a working voltage of 12V, which is provided by the tractor battery in the unit or the on-board electrical system.

The system is very similar to the one discussed in point III.1. The difference is that an AC motor (220 V) is used here. For its drive, an inverter is included in the system, which supplies 220V from 12V and controls the AC motor. As an example of such a voltage inverter PNI, L1200 W, input 12V, output 230 V can be used.

As in the DC motor mechatronic system discussed in Section III.1, the AC motor has a built-in encoder or tachogenerator that feeds information back to the microprocessor to make the necessary adjustments and adjustments to maintain the required shaft revolutions of the seed drills.

The configuration of a mechatronic system using an AC motor will look like the following figure 6.

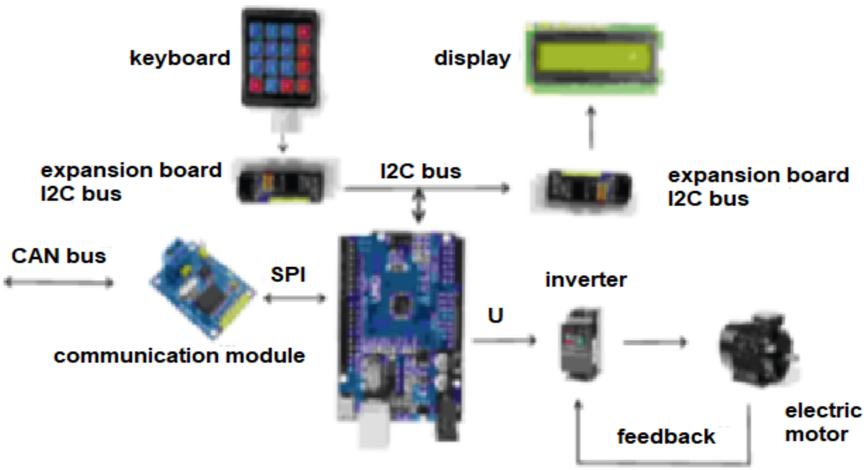

Fig.6. Device of the mechatronic system for regulating and maintaining the sowing rate with an asynchronous motor

The technical characteristics of the components used to build the mechatronic system are reflected in the appendices at the end of this work.

IV.3. Conclusions

1. Found the transmission function needed to set and maintain the seeding rate when working with a Saxonia 200A planter. It is directly dependent on the seeding rate and the amount of seeds sown in 1 revolution of the sowing device.

2. In order to switch to stepless adjustment of the sowing rate, a mechatronic system powered by the tractor's battery is implemented. It is possible to drive the seeders with a DC or AC motor.

3. The mechatronic system is designed in such a way that the signal for the unit's operating speed is taken from the tractor's computer.

4. When using a direct current electric motor, the mechatronic system is built on the basis of the microprocessor (microcomputer) Arduino. The executive unit is a DC motor (alternating current motor) with a built-in encoder or tachogenerator that feeds information back to the microprocessor to make the necessary adjustments and adjustments to maintain the necessary shaft revolutions of the drills.

V. EXPERIMENTAL RESEARCH

V.1. Determining the required power to drive the sowing devices of the Saxonia A200 planter

The required power is determined using the relationships in Section III. General research methodology, item III.1. The number of iterations for the mass of the arm, the mass of the weights and the gear ratio in the reducer is determined based on the accepted methodology. For each of the monitored indicators, 3 measurements were performed, after which the average value, variance and coefficient of variation were determined. The data from these measurements and their statistical processing are reflected in table 1.

Table 1. Results of preliminary trials

Monitored indicators	Test results			Results of statistical analysis		
	1	2	3	$\acute{x}$	σ	υ, %
Shoulder mass, kg	0,122	0,121	0,122	0,1217	3.33E-07	0,47
Mass of weights, kg	0,295	0,290	0,295	0,2933	8,33E-06	0,98
Gear ratio (634)	2	2	2	2	0	0

With the obtained values for the coefficient of variation, the number of repetitions is determined at a significance level α=0.05 and a relative error δ=5%. For the relevant indicators, they are:

- shoulder mass – 2;
- weight mass – 2;
- gear ratio – 1.

For greater reliability of the following results, it is assumed that the number of repetitions when determining these indicators is 5. After performing the final measurements, the following results were obtained, reflected in table 2.

Table 2. Values of monitored indicators

Monitored indicators	Test results					
	1	2	3	4	5	$\acute{x}$
Shoulder mass, kg	0,122	0,121	0,122	0,121	0,122	**0,1216**
Mass of weights, kg	0,295	0,290	0,295	0,285	0,295	**0,296**
Gear ratio (634)	2	2	2	2	2	**2**

Dependency 6 is used to determine the torque.

$$M = 9{,}81.\left(0{,}1216.\frac{0{,}615}{2} + 0{,}296.0{,}615\right) = 2{,}153Nm$$

The transmission of the torque is carried out by the running wheel of the planter through 3 chain and 2 toothed gears. The efficiency of each of them is in the range of 0.95-0.98. Taking into account the losses in the transmission, with an efficiency of the individual gears of 0.95, the required torque is determined by the following formula:

$$M_b = \frac{M}{0{,}95^5} = \frac{2{,}153}{0{,}774} = 2{,}782 Nm$$

According to formula 2.2 and the assumptions made in Section 2, the angular velocity of the driving wheel of the planter is:

$$\omega_{вх} = \frac{3{,}33}{0{,}29} = 11{,}48\ s^{-1}$$

To determine the general transmission ratio, a diagram (fig.1) of the transmission mechanism of the seeder was drawn up. The number of sprocket teeth involved in each intermediate gear is determined. The obtained data are reflected in the following table 3.

Table 3. Number of teeth on the gears of the transmission mechanism

Gear wheel	z_1	z_2	z_3	z_4	z_5	z_6
Number of teeth	32	16	37	22	16	32

Using the data from table 3 and formula 3 for the intermediate transmission ratios, the following values are obtained:

for the gear ratio of the first chain gear

$$i_{в1} = \frac{16}{32} = 0{,}5\ ;$$

for the gear ratio of the second chain gear

$$i_{в2} = \frac{22}{37} = 0{,}5946\ ;$$

for the gear ratio of the third chain gear

$$i_{в3} = \frac{32}{16} = 2\ ;$$

As already specified, the transmission ratio of the gear reducer at position 634 of the regulating mechanism is 2.

The total gear ratio of the transmission mechanism is a product of the intermediate values and from formula 5 is obtained:

$$i_{ПМ} = 0{,}5.0{,}5946.2.2 = 1{,}1892$$

It is known that the gear ratio is the quotient of the angular velocity of the input shaft to the angular velocity of the output. In our case, the input shaft is the shaft of the support (driving) wheel of the seeder, and the output shaft is the shaft of the seeders.

$$i_{ПМ} = \frac{\omega_{вх}}{\omega_{из}}$$

The above expression is solved with respect to the angular velocity of the output shaft and obtains:

$$\omega_{из} = \frac{\omega_{вх}}{i_{ПМ}} = \frac{11{,}48}{1{,}1892} = 9{,}65\ s^{-1}$$

With the torque and angular velocity results thus obtained, the power required to drive the seeders is:

$$P = M_b.\omega_{из} = 2{,}782.9{,}65 = 26{,}85W$$

From the result obtained for the power, an electric motor must be selected to drive the shaft of the seeders. There are two options for the implementation of the drive - with a direct current and with an asynchronous electric motor.

V.2. Amount (volume) of wheat seeds sown in one revolution of a toothed (pin) seed drill

The experiments to obtain the necessary information are conducted according to item III.2 of the present work with wheat seeds with a density of 825 kg/m3. Gears 111, 211, 231, 322, 431, 634 of the seeder's gear reducer were randomly selected. For each of them, a different number of revolutions of the crank for one complete rotation of the drive shaft of the seeders were performed. The results of these preliminary tests are presented in Table 4

Table 4 Preliminary determination of the number of revolutions of the crank for 1 revolution of the sowing apparatus

Gear in the reducer	Repetitions			Mean	Mean-square deviation	Koefficient of variation
	1	2	3			
111	141	140	141	**141,67**	0,577	0,410
211	70	71	70	**70,33**	0,577	0,821
231	44	44,5	44	**44,17**	0,288	0,654
322	22,5	22,5	22,5	**22,5**	0,00	0,000
431	11	11	11	**11,00**	0,00	0,000
634	2,5	2,5	2,5	**2,50**	0,00	0,000

It is noteworthy that for all gears the coefficient of variation has small values. This indicates a good clustering of the data, without much scatter. The largest value of the coefficient of variation is found at gear number 211. Normally, the largest number of repetitions is needed here. For this reason, the number of repetitions for that gear is determined first. According to the methodology, at the level of significance α=0.05, relative error δ=5% and coefficient of variation 0.821, the number of repetitions is 3.

For each of the selected gears in the gear reducer, the number of repetitions in determining this indicator is assumed to be 5.

After performing the final measurements, the results reflected in table 5 were obtained.

Table 5 Number of revolutions of the crank for 1 revolution of the sowing device

Gear in the reducer	Average number of revolutions
111	**141,0**
211	**70,0**
231	**44,0**
322	**22,5**
431	**11,0**
634	**2,5**

According to item III.2. from the General Methodology (formula 4), the data from the second column in table 5 represent the transmission ratio in the transmission system of the seeder from the second shaft (the crank is located on it) to the shaft of the sowing devices (fig.1).

According to the methodology reflected in item II.2, for each gear, 42 revolutions of the crank are performed. The sown amount of wheat seeds was collected and weighed. The results of the tests carried out are reflected below:

Table 6 Amount of seeds sown in 42 revolutions of the crank, g

Gear in the reducer	Repetition					Average
	1	**2**	**3**	**4**	**5**	
111	9	10	10	10	9	**9,6**
211	17	18	18	17	18	**17,6**
231	28	30	27	28	28	**28,6**
322	56	54	57	55	56	**55,4**
431	119	110	112	108	116	**113,0**
634	505	503	501	503	501	**502,4**

With a decrease in the transmission ratio, an increase in the amount of sown seeds is noticed (Table 6). This is logical, because reducing the transmission ratio increases the rotation speed of the sowing device and, accordingly, a larger amount of seeds is exported. What has been said so far is visualized and confirmed in the following Figure 6.

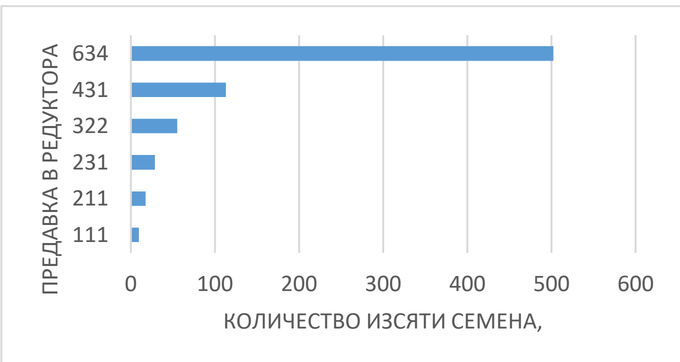

Figure 6 Variation of the seeded quantity depending on the gear in the reducer

Using formula 7, a certain amount of seed is sown for 1 revolution of the sowing device. The following results are obtained for the individual gears in the gearbox:

Table 7 Amount of seeds sown in 1 rotation of the sowing apparatus, g

Gear in the reducer	Repetition					Amount of seeds sown
	1	**2**	**3**	**4**	**5**	
111	30,21	33,57	33,57	33,57	30,21	**32,23**
211	28,33	30	30	28,33	30	**29,38**
231	29,33	31,43	28,29	29,33	29,33	**29,61**
322	30	28,93	30,54	29,46	30	**29,68**
431	31,17	28,81	29,33	28,28	30,38	**29,86**
634	30,06	29,94	29,82	29,94	29,82	**29,90**

With the data from Table 7, a comparison of the average values for the individual gears in the reducer was carried out at a significance level of p=0.01. The results of this analysis are reflected in the following table and figure

Table 8 Comparison of average values for the amount of seeds sown at different gears

T-test for Independent Samples, Note: Variables were treated as independent samples					
	Mean 1	**Mean 2**	**t-value**	**df**	**p**
111 vs. 211	32,226	29,332	3,149	8	0,014
111 vs. 231	32,226	29,542	2,767	8	0,024
111 vs. 322	32,226	29,786	2,813	8	0,023
111 vs. 431	32,226	29,594	2,696	8	0,027
111 vs. 634	32,226	29,916	2,802	8	0,023
211 vs. 231	29,332	29,542	-0,320	8	0,757
211 vs. 322	29,332	29,786	-0,922	8	0,383
211 vs. 431	29,332	29,594	-0,394	8	0,704
211 vs. 634	29,332	29,916	-1,419	8	0,194
231 vs. 322	29,542	29,786	-0,419	8	0,686
231 vs. 431	29,542	29,594	-0,071	8	0,945
231 vs. 634	29,542	29,916	-0,726	8	0,488
322 vs. 431	29,786	29,594	0,324	8	0,754
322 vs. 634	29,786	29,916	-0,468	8	0,652
431 vs. 634	29,594	29,916	-0,611	8	0,558

From the data in Table 8, it can be seen that there is no proven statistical difference between the sown amounts of seeds in the different gears at a significance level of p=0.01. This gives reason to accept the hypothesis that the quantities of seeds sown in 1 revolution of the sowing apparatus, in the different gears, are from one general set.

The above is well illustrated in Figure 7, where it can be seen that for all gears from 211 to 534 the data is almost the same, with a large overlap of the bands in which they are located. Only in gear 111 is this overlap significantly less, but it is also available.

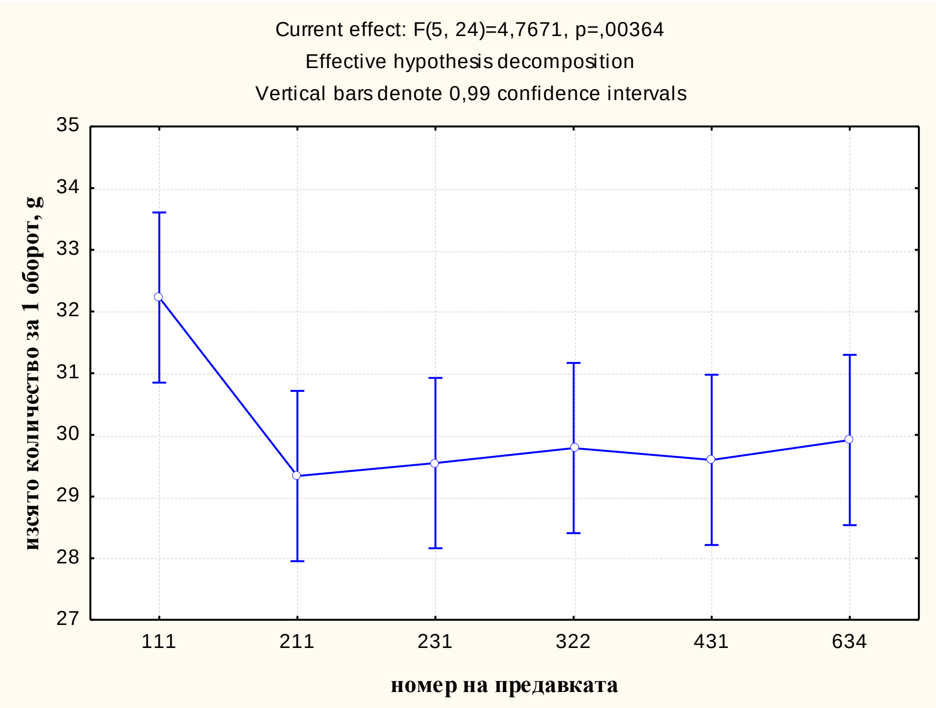

Figure7 Comparison of the average values of the number of seeds sown for 1 rotation, g

The average value of the amount of wheat seed sown in 1 revolution of the seeder is 30.067 g.

With the data from Table 7, a variation analysis was carried out and the dispersion was determined (σ=1.11). the root mean square deviation (1.05) and the coefficient of variation (υ=3.50). From the measurements and statistical analysis performed, it is found that the data are well clustered around the mean, with negligible scatter.

For greater certainty in the obtained results, a check was made for gross errors in the measurements, according to the methodology proposed by the authors (A. Mitkov, D. Minkov, 1989). At a significance level α=0.01 and the number of measurements n = 6, the threshold value of the gross measurement error criterion is V_T = 2.13. The calculated values of this criterion for the minimum (29.38) and the maximum (32.23) amount of seeds sown in 1 revolution of the seeder are respectively $V_{29.38}$ = 1.434 and $V_{33.23}$ = 2.01, which gives reason to claim , that there are no gross errors in the measurements made, which would significantly distort the obtained results and lead to incorrect conclusions in the subsequent activities of the doctoral work.

The density of the wheat seed material used is 825 kg/m3. According to formula 9, the volume of seeds sown in 1 revolution of the sowing apparatus is 0.0000371758 m^3.

V.3. Determination of the functional relationship between the gear ratio in the transmission mechanism, seed density and the amount of seed sown

From the measurements made earlier, the transmission ratio from the second shaft of the transmission system to the shaft of the seeders was established.

Table 9 Transmission ratio between the second shaft and the shaft of the sowing apparatus

Gear in the reducer	Gear ratio
111	**141,0**
211	**70,0**
231	**44,0**
322	**22,5**
431	**11,0**
634	**2,5**

The total gear ratio will be obtained as a product of the gear ratio of the chain gear from the drive wheel to the second shaft and the gear ratio shown in Table 9. According to formula 3 and Figure 5, the transmission ratio of the chain gear is:

$$i_{\text{в}}=\frac{z_2}{z_1}=\frac{16}{32}=0{,}5$$

After the calculations, the general transmission ratio from the driving wheel of the seeder to the shaft of the seeders is indicated in table 10.

Table 10 Gear ratio for the different gears in the reducer

Gear in the reducer	Gear ratio
111	**70,50**
211	**35,00**
231	**22,00**
322	**11,25**
431	**5,50**
634	**1,25**

When determining the upper, lower and middle levels of this factor, we are guided by the rule that the distance between them should be approximately the same. Assuming the upper level is 70.5 (at 111 gear) and the lower is 1.25 (at 634 gear) with some approximation the average level will be 35 (at 211 gear).

For the density, according to item III.4, seed materials with a bulk weight of 250, 537 and 825 kg/m^3 were selected.

As a consequence of the above, the plan of the experiment takes the form (Table 11):

Table 10 Plan of the experiment

Factors	
Gear ratio	*Density of the seeds, kg/m^3*
70,50	825,00
70,50	250,00
1,25	825,00
1,25	250,00
35,00	825,00
35,00	250,00
70,50	532,00
1,25	532,00

According to the adopted methodology, measurements were carried out at each point of the experiment, in 5-fold repeatability. The results are obtained from the operation of only 1 seeder. If it is necessary to know the amount of seeds sown by the entire planter, then the data reflected in the following table must be multiplied by the number of sowing devices of the observed planter.

The averaged data from the experiments are presented in table 12.

Table 12 Averaged data from the experiments

Factors		*Amount of seed sown in 42 revolutions, g*
Gear ratio	*Density of the seeds, kg/m^3*	
70,50	825,00	9,6
70,50	250,00	3
1,25	825,00	502,4
1,25	250,00	151,4
35,00	825,00	17,6
35,00	250,00	5,6
70,50	532,00	6
1,25	532,00	322

It can be seen that as the density increases, the amount of seeds sown increases linearly. This is logical, because with the same number of revolutions, the seeder puts out the same volume of seeds. The greater the density multiplied by this volume will give a correspondingly greater quantity (greater weight) of the seeds.

On the other hand, with a reduction in the transmission ratio, the output shaft of the reducer starts to rotate faster (with a greater speed), respectively the shaft of the sowing apparatus. This results in a greater amount of seed being delivered at the same revolutions of the running (driving) wheel.

The conducted factor analysis (Table 13) gives reason to claim that the transmission ratio has a stronger impact on the change in the sown amount of seeds compared to the seed density. About 61.1% of this variation is due to the gear ratio. 33.3% were influenced by seed density. In conclusion, 94.4% of the variation in the amount of seed sown was due to the two factors. Only 5.6% of this change was due to other factors not reported in the current study. According to leading authors, this is a prerequisite to run a regression analysis with only these 2 factors (seed density and gear ratio).

Table 13 Factor analysis

Eigenvalues (Density, Gear ratio) Extraction: Principal components				
	Eigenvalue	**% Total**	**Cumulative**	**Cumulative**
Gear ratio	1,832790	61,09301	1,832790	61,09301
Density of the seeds	0,999973	33,33243	2,832763	94,42544

With the averaged data from table 12, a regression analysis was conducted using the Statistika v.7 software product. Its results are presented in table 14.

Table 14 Results of the regression analysis

Regression Summary for Dependent Variable: R= 0,98407964; R^2= 0,96841273; Adjusted R^2= 0,93682547; F(4,4)=30,658 p<0,0029						
	Beta	**Std.Err.**	**B**	**Std.Err.**	**t(4)**	**p-level**
X	-1,71106	0,554431	**-7,99908**	2,591925	-3,08615	0,036711
Y	1,67096	0,151774	**0,61569**	0,055923	11,00951	0,000387
X^2	1,79711	0,521588	**0,12608**	0,036592	3,44546	0,026163
X.Y	-1,28815	0,247045	**-0,01023**	0,001963	-5,21424	0,006453

X – Gear ratio, Y – Density of the seeds, kg/m^3

The resulting model has the form:

Z=-8*X+0.616*Y+0.126*X2-0.010*X*Y

With its help, the regression surface presented in the next graph, were constructed.

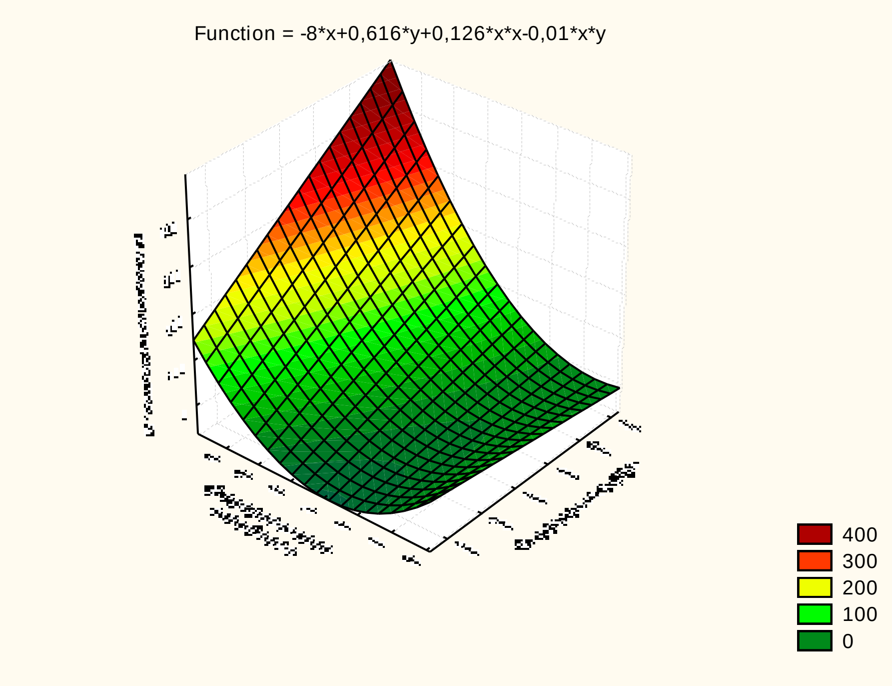

Figure 8 Regression surface for the relationship between transmission ratio, seed density and the amount sown

V.4. Determining reduced operating costs depending on the transmission mechanism used in the row drill (mechanical or electronic) when sowing cereals with a "fused surface".

A seed drill similar to the Saxonia A200 seed drill, with a 3 m working width, was chosen as the basic model. The driving of the seeders is carried out by the running wheel by means of a variator. The price of the seeder is BGN 14,000, and only the variator costs BGN 450. It is possible to replace the variator with a 32-speed gear reducer, the price of which is BGN 1,235. With this option, the price of the seeder is BGN 14,785. Mechatronic system for sowing rate control standard includes a controller, frequency regulator, tachometer and DC motor, costing BGN 45, 350, 23, 150 respectively. The total price with wiring and labor is BGN 730. The price of the seeder equipped with a mechatronic system is BGN 14,280.

For the current calculations, a MF4708M tractor with a base price of BGN 159,430 was selected.

Annual deductions for depreciation and overhaul of the planter are 20% of the acquisition price (with a 5-year buyback period), those for current repair and maintenance — 16%. For the tractor, these deductions are respectively 10% for depreciation and major repairs and 16% for current repairs and maintenance. When calculating the operating costs of the unit for deductions for depreciation and major repairs, 1/6 of their total value is taken for the tractor and 100% of those for the planter.

The total amount of these deductions for the different types of drive are changed as follows: with a variator — BGN 11,948.63/year, with a gear reducer — BGN 12,231.23/year and with a mechatronic system — BGN 12,049.43/year.

From the surveys carried out in the Pazardzhik region, it was established that the salary of the mechanic is BGN 100-125/day, and that of the support worker - BGN 50-60. The FRZ was accepted for the mechanic - BGN 125, and for the service worker - BGN 55 .for a day.

The cost of fuel-lubricants is the cost of basic fuel and its complex price. The complex price is the value of 1 kg of fuel and the corresponding quantities of lubricants, calculated as a percentage of the main fuel. The price of diesel fuel is BGN 3.33/l. This price is multiplied by 1.2 to convert to a price per 1 kg and the resulting number is multiplied by 1.06 to obtain the complex price of 1 kg of diesel fuel, namely BGN 4.236/kg. With an average consumption of 0.28 kg/dka, the fuel price is BGN 1.186/dka.

The cost of tires is BGN 6,300 per set. One set is usually used for 2 years. From here it follows that for a year this expense is BGN 3150.

The use of the planter during the year is about 40 days. The hourly productivity is the product of the working width — 3 m, the travel speed — assumed to be 12 km/h, and the utilization factor of the working speed, working width and working time — 0.8. making 28.8 dka/h. With an 8.5 h duration of the working day, the daily productivity is 244.4 dka. The seasonal (annual) productivity is 9776 dka. Productivity is not affected by the type of drive of the seed drills.

The cost of fuel and lubricants as a product of the complex price of fuel and seasonal productivity is BGN 11,594.336. For the wages of the operator and auxiliary worker, this cost is BGN 8,533.44. The costs of feathers, operating and reduced operating costs are reflected in the following table.

Table 15 Reported operating costs in total and per feather, BGN/year

	ОАТРП	**ГСМ**	**ФРЗ**	**Г**	**ЕР**	**ПЕР**
with variator	11948,63	11594,34	8533,44	3150,00	35226,53	3,603
with reducer	12231,23	11594,34	8533,44	3150,00	35509,13	3,632
with a mechatronic system	12049,43	11594,34	8533,44	3150,00	35327,33	3,614

ОАТРП – deductions for depreciation, current repair and maintenance, ГСМ – costs for fuel and lubricants, ФРЗ – wage fund, Г – tire costs, ЕР – operating costs, ПЕР – reduced operating costs

It can be seen that with the largest share are the expenses for OATRP and GSM - respectively 34 and 33% of the ER (figure 9). Close to them are the expenses for FRZ - 24%, and the relatively smallest expenses for D - 9%. This is due, on the one hand, to the large volume of work that is carried out during the year with the seeder, and on the other hand, the relatively low price of its acquisition. The operating costs are almost the same, respectively the reduced operating costs (figure 10), for the three options considered, since there is a minor difference in the OATRP due to the drive system of the seeders.

The percentage distribution of feather costs is presented in the following chart.

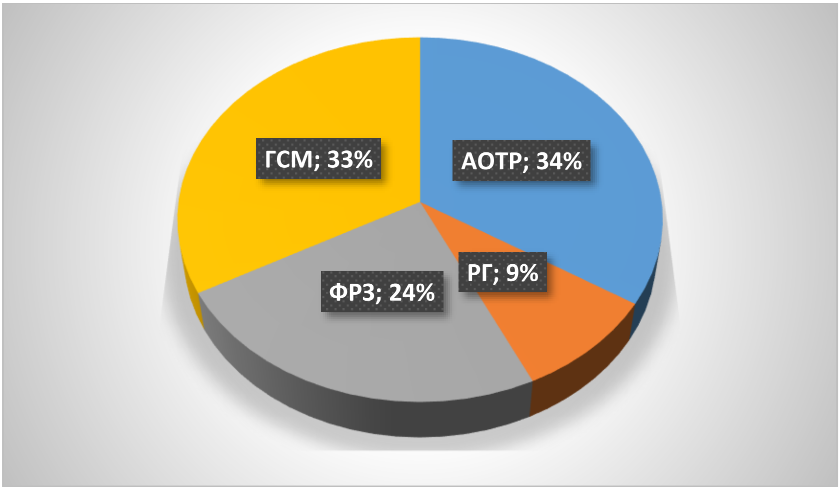

Figure 9 Distribution of costs by feathers

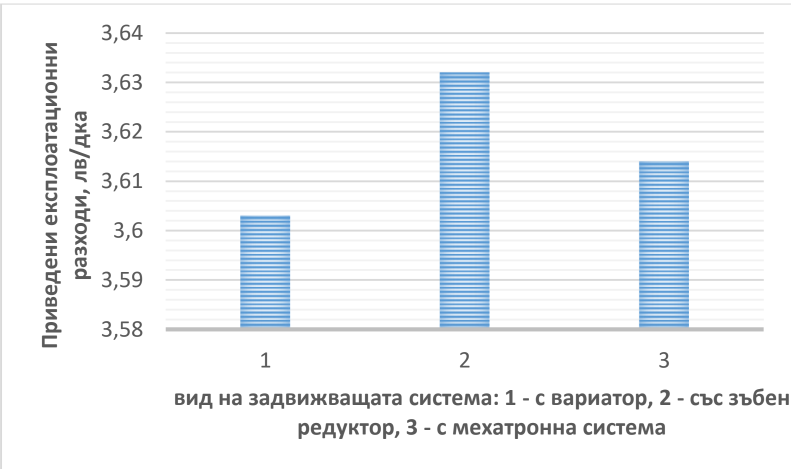

Figure 10 PER depending on the propulsion system

V.5. Conclusions.

1. The angular speed of the seed drills shaft (9.65 s^{-1}), the torque (2.782 Nm) and the power for its drive (26.85 W) were determined. From the result obtained for the power, an electric motor must be selected to drive the shaft of the seeders. There are two options for the implementation of the drive - with a direct current and with an asynchronous electric motor.

2. The amount of wheat seeds, at a density of 825 kg/m3, sown for 1 revolution of the sowing device is 30.067 g.

3. As the density increases, the sown quantity of seeds increases linearly, and as the transmission ratio decreases, the output shaft of the reducer, respectively, the shaft of the sowing apparatus, starts to rotate faster (with a greater speed). This results in a

greater amount of seed being delivered at the same revolutions of the running (driving) wheel. The gear ratio has a stronger effect on the variation in the amount of seed sown than the seed density. About 94.4% of the variation in the amount of seed sown is due to the two factors. Only 5.6% of this change was due to other factors not reported in the current study.

4. With the largest share are the expenses for OATRP and GSM, close to them are the expenses for FRZ, and the relatively smallest expenses are for D. This is due, on the one hand, to the large volume of work that is carried out during the year with the seeder and the relatively low cost of acquiring it from another. The operating costs are almost the same, respectively the reduced operating costs, for the three options considered, as there is a minor difference in the OATRP due to the drive system of the seeders.

VI. GENERAL CONCLUSIONS

The following conclusions can be drawn from the literature review, theoretical and experimental research and further processing of experimental data and analysis:

1. In agricultural practice, when sowing cereals with a "fused" surface, toothed and oil seed drills are widely used;

2. In the used row drills, the drive of the sowing devices is carried out with mechanical or mechatronic systems.

3. The volume weight of the sown materials varies in very wide limits, from 300 to 900 kg/m3, and in the studied literature there is not enough data on its influence on the sowing rate.

4. With the help of the conducted theoretical research, the transmission function necessary for setting and maintaining the sowing rate when working with a Saxonia 200A seed drill was determined - $i = \frac{Q}{4575{,}74.q_{об}}$. It is directly dependent on the seeding rate and the amount of seeds sown in 1 revolution of the sowing device. The transmission function is the basis of a mechatronic system for stepless adjustment of the sowing rate, powered by the tractor battery. The signal for the unit's operating speed is taken from the tractor's computer. When using a direct current electric motor, the mechatronic system is built on the basis of the microprocessor (microcomputer) Arduino. The executive unit is a DC motor with a built-in encoder or tachogenerator that feeds information back to the microprocessor to make the necessary adjustments and adjustments to maintain the necessary rotations of the planters shaft.

5. The angular velocity of the seeders shaft (9.65 s^{-1}), the torque (2.782 Nm) and the power for its drive (26.85 W) were determined. From the result obtained for the power, an electric motor must be selected to drive the shaft of the seeders. There are two options for the implementation of the drive - with a direct current and with an asynchronous electric motor.

6. The amount of wheat seeds, at a density of 825 kg/m3, sown in 1 revolution of the sowing device is 30.067 g.

7. A mathematical model was developed for the influence of seed density (Y) and transmission ratio (X) on the amount of seed sown.

Z=-8*X+0.616*Y+0.126*X2-0.010*X*Y

The model is adequate at a significance level of p<0.0029 and can be used to solve optimization and other research tasks.

8. As the density increases, the sown quantity of seeds increases linearly, and as the transmission ratio decreases, the output shaft of the reducer, respectively, the shaft of the sowing device, starts to rotate faster (with a greater speed). This results in a greater amount of seed being delivered at the same revolutions of the running (driving) wheel. The gear ratio has a stronger effect on the variation in the amount of seed sown than the seed density. About 94.4% of the variation in the amount of seed sown is due to the two factors. Only 5.6% of this change was due to other factors not reported in the current study.

9. With the largest share are the expenses for OATRP and GSM, close to them are the expenses for FRZ, and relatively the smallest are the expenses for D. This is due, on the one hand, to the large volume of work that is carried out during the year with the

seeder and the relatively low cost of acquiring it from another. The operating costs are almost the same, respectively the reduced operating costs, for the three options considered, as there is a minor difference in the OATRP due to the drive system of the seeders.

VII. CONTRIBUTIONS

V.1. Scientific and theoretical contributions

1. The transmission function in a mechatronic system controlling and supporting the process of sowing seeds in the Saxonia A200 planter was theoretically determined. The variables in it are the sowing rate and the amount of seeds that are sown in 1 revolution of the sowing apparatus, which is directly dependent on their density and volume.

2. The functional relationship between seed density, transmission ratio and the amount of sown seeds was established. A mathematical model has been developed that is adequate and can be used to solve optimization and other research tasks.

3. A methodology has been developed for determining the main parameters of the electric drive of the sowing devices of the Saxonia A200 planter.

V.2. Scientific and applied contributions

1. 2 versions of a mechatronic system for controlling the sowing rate have been developed - with a DC and an AC motor. At the core of both variants is the Arduino microprocessor (microcomputer), which is a tool for developing devices that interact with the physical environment. It is an open hardware and software platform for working with physical objects.

2. The amount of wheat seeds sown in 1 revolution of the toothed (pin) sowing device of the Saxonia A200 seeder was determined – 30.067 g.

3. The gear ratio was found to have a stronger effect on the variation in seed rate compared to seed density. About 61.1% of this variation is due to the gear ratio. 33.3% were influenced by seed density. A total of 94.4% of the variation in the amount of seed sown was due to the two factors. Only 5.6% of this change was due to other factors not taken into account.

4. It has been proven that the type of drive system (mechanical or electric) of the seeder's sowing devices does not have a significant impact on the reduced operating costs. 2/3 of these costs are deductions for depreciation, major and current repairs, ¼ for the formation of a salary fund and about 1/10 for fuel.

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