PRECISION AIR SEEDER FOR HEMP – CONTROL SYSTEM SIMULATION

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Abstract. Hemp is useful in many aspects of human life: medicine, nutrition, industry, construction, etc., that is why hemp cultivation in Europe is increasing. Various techniques are used to sow hemp. The University of Life Sciences in Lublin conducts research on the use of the precision air seeder for hemp. The paper presents simulation tests of the control of the DC (Direct Current) motor used in this type of seeders. A method for selecting PWM (Pulse Width Modulation) of DC motor frequency is presented.

Keywords: precision seeders, hemp, control of DC motor.

Introduction

There is a great demand for hemp products in the pharmaceutical, cosmetics, food and construction industries. Growing hemp does not require intensive fertilization or the use of plant protection products, and its two-and-a-half-meter-deep root system improves the quality of the soil. The hemp is cultivated to rebuild the vitality of the soil and constitutes a valuable forecrop. The flowers and seeds are processed into health-promoting products, and the dried leaves are made into herbal teas. Straw can be used as green fertilizer or processed into paper pulp or even hempcrete. The European Union Parliament passed amendments increasing the legal THC (Tetrahydrokannabinol) level from 0.2% to 0.3% [1]. This will probably increase the popularity of hemp (*Cannabis sativa* L.) cultivation [2]. The increase in the demand for hemp means that more and more areas will be devoted to cultivation. Research work related to the technology of growing this plant has been intensified, aimed at improving the yield and quality of the plant. There is a demand for modernization and construction of new agricultural machines for sowing and cultivation of hemp. A cultivation and sowing unit is designed and built in strip-till technology with variable dosage of fertilizers, enabling sowing of seeds at different row spacing and using field mapping (GPS - Global Positioning System). An important stage of this work is the assessment of the suitability of the proposed unit for various soil conditions.

The designed and built machine requires to take into account many construction and organizational factors. Knowledge of the properties of seeds (bulk materials) and the properties of construction materials is necessary [3; 4]. Operational and reliability parameters are very important because the machine periodically works with very high random loads [5; 6]. Quickly wearing parts of the machine are made of sintered materials that are designed and manufactured using new technologies [7]. The coulter introducing seeds into the soil wears out quickly, research is carried out using various materials sintered using the electroconolidation method [8]. Machine damage risk analysis is conducted on a permanent basis (all the time) using various methods (e.g. FMEA – Failure Mode and Effect Analysis) [9-14]. According to the idea of industry 4.0 (agriculture 4.0), it is planned to use Internet technologies to produce spare parts “in the field” using 3D printing [15].

One of the important tasks of machine construction is the synthesis of the control system. Process modeling is helpful in this task [16-19]. The difficulty in obtaining a high-quality process (precision and repeatability) is transport delay and non-linearity [20-22]. In such situations, control with a process model, robust control, is used. Market diversity and continuous development of control systems require extensive knowledge that must be constantly updated. The paper presents the results of a simulation of the operation of a sowing section using a DC motor. The modeling of DC electric motors and the use of the PWM signal is widely known, but it is constantly improved [19]. The design of the seeding section control system was developed using the ARDUINO controller. The paper presents the mathematical model of a DC motor, taking into account the speed signal of an agricultural tractor – see Fig. 2. The model was written in state space. This will enable further testing of the control system, perhaps IMC (Internal Model Control) or Robust Control will be used. The decision will be made after preliminary field tests.

The simulation results showed that the minimum frequency of the PWM signal will be 50 Hz for the planned engine. It will be possible to control and program it using the popular MATLAB program.

The mechanical design of the sowing section is widely known, but it is used for other types of seeds than hemp.

The aim of the research is to develop a much cheaper control system than is available on the market (manufacturers protect the technical details of control systems), develop and test advanced control algorithms and popularize the research results.

Materials and methods

The research concerns the synthesis of the control system for the section sowing hemp seeds. Laboratory tests include selection and programming of a PLC controller, selection and programming of a PWM controller using SIMULINK Matlab, selection of a DC motor amplifier, selection of technological parameters for hemp sowing.

The recommended minimum temperature for sowing hemp is 8 ºC at a depth of 3-4 cm. Fibrous hemp varieties are sown in 11-12 cm inter-rows at a rate of 60 kg·ha^{-1}. Crops for technical fiber and cellulose are 40-50 seeds kg·ha^{-1}, and for biomass – 30 kg·ha^{-1}. Seed varieties are sown at 20-25 kg·ha^{-1}, oil varieties are sown at 40 kg·ha^{-1} at a row spacing of 25-30 cm [23]. These values are the basis for selecting the distance between the sown seeds. Henola is one of the varieties planned for the research. The height of mature Henola plants reaches 170-200 cm. It also has a vegetation period that is approximately 3 weeks shorter than for other varieties (115-120 days after sowing). The variety yields 1.5-2.1 t·ha^{-1}, and the seeds have a very favorable fatty acid ratio [24].

A fragment of the seeding unit under construction (strip tillage coulter system without seeding mechanisms) is shown in Fig. 1.

Fig. 1. **Fragment of a set for growing and strip sowing of hemp without seeding mechanisms, constructed at Roltex, fot.Roltex [26]**

One of the tasks of precision sowing is to place the seeds at a predetermined distance in the row (path) (size "y" Fig. 2). There are several different drive solutions on the market. One of them is the use of a drive (PWM DC engine) for each section. This solution has the ability to copy the field profile for each (independently) section. Due to the topography of the experimental fields, this solution was chosen to complete the task.

The motor rotation speed (Fig. 2) depends on the speed of the seeding unit integrated with the agricultural tractor v[m·s^{-1}].

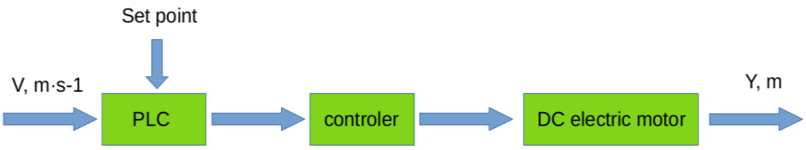

Fig. 2. **Scheme of the control system:** v – unit speed; y – distance between seeds in a row

A Siemens PLC controller, model S7-1200, was used to carry out the task. The construction of the sowing section with a marked DC motor controlled by a PWM signal is shown in Fig. 3 [25]. The PWM signal is generated by the ARDUINO controller, the set value is calculated in the PLC (programmable logic controller) controller based on the speed of the tractor (aggregate) and is sent to the input of the ARDUINO controller via the analog output of the PLC controller. In the ARDUINO controller, the 5V signal is amplified using a module and then this signal powers the DC motor.

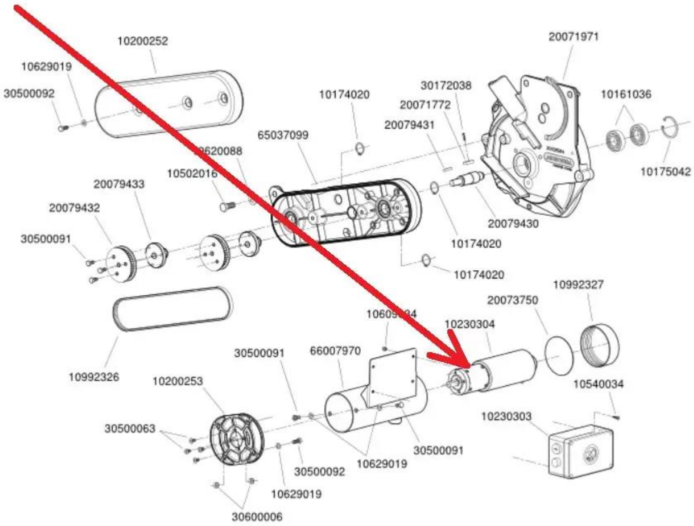

Fig. 3. **Construction drawing of the sowing section**

The selection of the PWM signal frequency and fill was carried out through simulations in programs Matlab and Simulink.

The electric motor in the sowing section is an executive element in the system controlling the rotational speed of the rotor, which affects the spacing (distances) between the sown seeds (control system output y). The input of the entire control system is the speed of the agricultural tractor (aggregate). In the first stage of the research (analyzed in this paper), only part of the control system was adopted, in which the input value is the voltage applied to the motor and the output value is its rotational speed, in order to initially estimate the PWM frequency.

Using Kirchhoff's second law for the armature circuit, the formula can be written [19]:

$$u = R_w \cdot i + L_w \frac{di}{dt} + k_e \cdot \omega, \tag{1}$$

where u – voltage, V;
R_w – resistance of armature circuit, Ω;
i – curent, mA;
L_w – induction, H;
k_e – motor electromotive constant, $V \cdot s \cdot m^{-1}$;
ω – rotor angular speed, $rad \cdot s^{-1}$.

The second equation is obtained by equating the torque developed by the rotor to the sum of the engine own torque and the torque from the load [19].

$$k_m \cdot i = J \frac{d\omega}{dt} + B \cdot \omega, \tag{2}$$

where k_m – motor torque constant, $N \cdot m \cdot A^{-1}$;
J – total moment of inertia of the motor and load, $N \cdot m \cdot rad^{-1} \cdot s^{-2}$;
B – viscous friction coefficient, $N \cdot m \cdot rad^{-1} \cdot s^{-1}$.

Equations 1 and 2 are written in the form:

$$\frac{di}{dt} = \frac{-R_w}{L_w} \cdot i - \frac{k_e}{L_w} \cdot \omega - \frac{u}{L_w} \tag{3}$$

$$\frac{d\omega}{dt} = \frac{k_m}{J} \cdot i - \frac{B}{J} \cdot \omega \tag{4}$$

Based on the above equations, a simulation model was created in Simulink (Fig. 4).

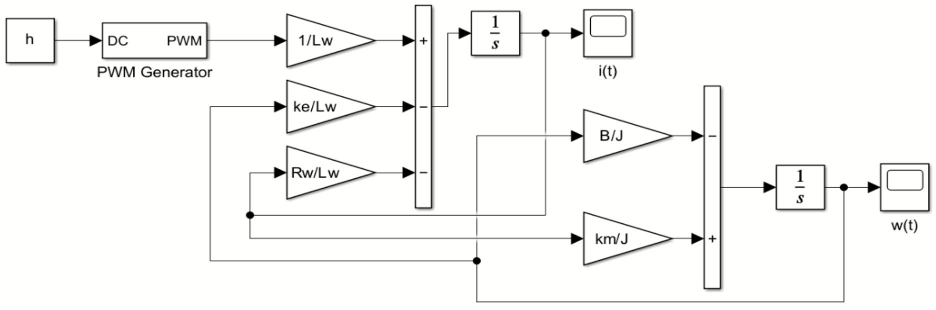

Fig. 4. **Diagram of the simulation program**

The simulations were intended to select the frequency and fill of the control signal. The Simulink program will be used to program the ARDUINO controller.

Results and discussion

Simulations were carried out based on the engine catalog data (R_w = 2; L_w = 0.1; k_e = 0.1; J = 0.1; B = 0.5; k_m = 0.1). Fig. 5 shows the results of simulation tests for frequencies of 5, 25 and 50 Hz. The use of 5 Hz and 25 Hz frequencies is inappropriate due to uneven engine operation. The motor with the given parameters has the properties of a second-order inertial element. The output signal oscillations are caused by the forcing signal.

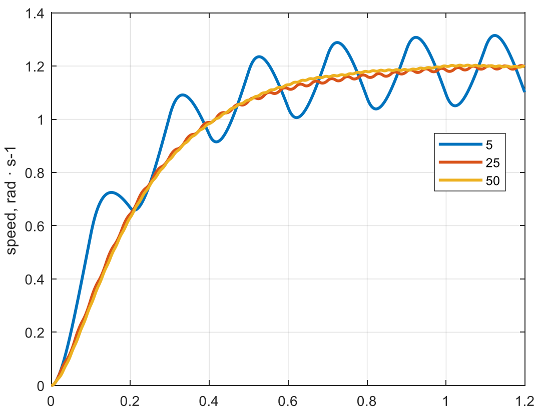

Fig. 5. **Angular velocity values (rad·s^{-1}) for a frequency 5Hz, 25 Hz and 50Hz, filling 50%**

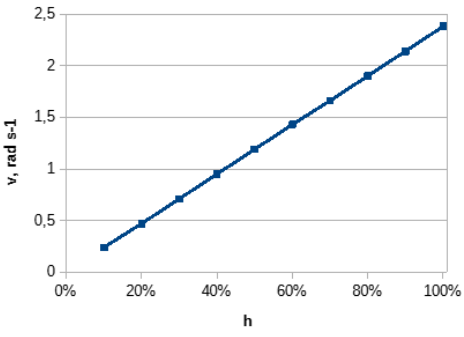

Fig. 6. I**nfluence of the control signal filling (h) on the engine speed, rad·s^{-1}**

The modeled system has the operator transfer function of the second-order inertial term (eq. 5).

$$G(s) = \frac{0.1}{0.01s^2 + 0.25s + 1.01}, \tag{5}$$

Based on the obtained graph, it can be assumed that the equivalent time constant is approximately 0.3 sec. The engine speed will stabilize after approximately 1 second. This is not a large value and will not affect the quality of sowing. The results show that the PWM frequency of 25 Hz is a bit too low. The frequency of 50 Hz was used for further analysis. The characteristics of the engine rotational speed depending on the control signal fulfilment (h) are presented in Fig. **Error! Reference source not found.** (for 12, V).

Conclusions

1. The discussed control system can be described using differential equations on the basis of which it can be modelled. The engine has the properties of a second-order inertial element. The simulation results enabled the selection of control system parameters such as the frequency and degree of filling of the control signal. Based on the test results, the minimum frequency was assumed to be 50 Hz.
2. The last phenomenon studied was the regulation of the rotor rotational speed using the modulation pulse width (PWM). A proportional increase in the average rotational speed was observed depending on the duty cycle of the voltage signal.
3. The obtained simulation results require verification on a laboratory stand, for this purpose a control system will be assembled. The linearity of the system will be examined.
4. The proposed control devices are much cheaper than the devices offered by agricultural machinery manufacturers. Both the PLC and ARDUINO controller can be connected via the Internet, which is compatible with agriculture 4.0.

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