Travel printer with positional stepper motor control

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Abstract. A new technical solution of the road printer proposed to improve the efficiency of the device and reduce the complexity in the application of complex graphic images on asphalt concrete pavement to improve road safety was considered. The results of theoretical studies of the “Road Printer” project with the implementation of a simulation model of the automatic control system for a stepper motor of a road printer using the MATLAB & Simulink software are presented. The results of modeling a control system model with synthesized parameters of the proportional-integral-differentiating (PID) controller are given.

Introduction
When designing roads, it is important to ensure the regulatory compliance of the markings and road signs, traffic lights and other means of traffic organization. According to GOST R 51256-2011 “Road markings”, the road signs are executed in a straight and figured form [1]. The modern high-tech equipment from mobile hand markers to special equipment installed on the chassis of trucks is used for marking [2]. The disadvantage of the existing technology is the implementation of time-consuming and inefficient manual work when applying curly characters. The automated road printer should be used for the application of complex curly signs on road markings. The stepper motor control issues were considered in [3-5]. The requirement for the operation of a road printer with stepper motors guarantees stability of the drive system. These questions are not reflected in the well-known works. The questions of automating the process of applying complex patterns to the surface of the territory were taken up by the foreign scientists [6-7]. They have developed and investigated the systems for the application of simple drawings. In this connection it was necessary to improve the control system of the drives of a road printer, to study a control system with a proportional-integral-differential (PID) regulator for stability.

Objective: theoretical analysis of the work process of a road printer and parametric synthesis of a regulator of a stepper motor control system of a road printer.

Materials and methods
To ensure the high requirements for the road safety, a road printer has been proposed [8]. The road printer is intended for drawing dividing strips and difficult images of the big sizes on a roadbed. The technical result when using a road printer is to increase the efficiency of the device and reduce the complexity.

Road printer, see: figure 1, works as follows. For the application of the figured image on the road pavement, the road printer is driven along the road by means of the carriage 1 with stepper motors 5. At the same time, the moving carriage 3 along the drop guides 2 start moving in a reciprocating manner...
across the road. The downloaded figure files in the control device 7 and is converted into J-code by means of a program code. In the process of moving the road printer, the figured pattern is applied by supplying paint with the nozzle 4 from the ink tank 6.

Figure 1. Road printer
1 - carriage; 2 – drop guides; 3 - movable carriage; 4 - nozzle; 5 - stepper motor; 6 – ink tank; 7 - control device

The main technical and other requirements for the road printer:
- working paint pressure at the spray gun outlet: 120-230 MPa;
- principle of operation: similar to a printing plotter;
- control of automated equipment - remote control (RC);
- software compatibility with COREL DRAW, AutoCAD;
- the ability to print on the pavement of letter and character images with a width of at least 1.85 m;
- geometric printing accuracy: ± 1.0 cm.

The drive mechanisms for moving the printer and the movable carriage are driven by a stepper motor with a PID control system controller.

The mathematical model of the stepper motor is given in the form of the equations of the anchor chain, the driving moment for the rotational motion, as well as the reduced mass.

\[
U_d = R_s i_d + L \frac{d i_d}{dt} - z_p \omega L_s i_q
\]

\[
U_q = R_s i_d + L \frac{d i_d}{dt} - z_p \omega L_s i_q + z_p \omega \phi_q
\]

\[
I \frac{d \omega}{dt} = M - M_e
\]

\[
M = \frac{3}{2} z_p \phi_q i_q
\]
$$M_c = Rm_{np} a + f(m_1 g + 2mg),$$

$$m_{np} = m_1 + 2m_2 + \frac{2(1 + I \partial_\phi)}{R^2},$$

(5) (6)

Where $U_d$ is the motor voltage; $R_s$ - engine resistance; $i_d$ - motor current; $L_s$ - inductance of the excitation winding; $z_p$ - reduced resistance; $i_q$ - armature current; $U_q$ - tension of the armature; $\omega$ - angular velocity; $\phi_p$ - phase angle; $M$ - load moment; $M_c$ - moment of resistance; $m^{pr}$ is the reduced mass of the road printer; $f$ is the rolling friction coefficient of the wheels; $I^f$ is the moment of inertia of the wheel about its axis; $f^e$ - the moment of the engine inertia; $M^f$ - the required torque on the motor shaft; $R$ is the radius of the wheels; $m^i$ is the mass of the carriage; $m^2$ is the mass of the wheels; $a$ is acceleration.

In the drive control system of a printer with a stepper motor, the PID controller is used to increase and define the work in the steady state. As an assumption the effect of counter-EMF is negligible. To adjust the controller, an operator form was used with the inverse of the product of the transfer function of the forward branch and the feedback branch of the control loop. The inertia of the converter cannot be compensated; therefore, it is excluded from the synthesis.

The transfer function of an ideal PID controller is:

$$W_{PID}(s) = K_p + \frac{K_I}{s} + K_D s,$$

(7)

where $K_p$, $K_I$, $K_D$ are the parameters of proportional, integral and differentiating element of the regulator, respectively; - the operator.

The model of drive control of a road printer, compiled in MATLAB * Simulink is shown in Figure 2.

![Figure 2. Model of the drive control of a road printer, compiled in MATLAB * Simulink](image_url)

The function block of the Function Block Parameters environment of the Simulink environment is shown in figure 3.
Figure 3. The panel of the functional block of the stepper motor control model with PID controller

The results of the stepper motor control model implementation process with a PID regulator are shown in Figure 4.

Figure 4. Transitional characteristic of the management process

The results of the simulation of the control process of a stepper motor with a PID-controller showed that transients of the drive of an oscillating-type road printer are its characteristics. The form of oscillations is non-sinusoidal and increases with increasing amplitude of oscillations. PID override is not available. At the same time the regulation time does not exceed 0.036 sec. The stability assessment of the stepper motor drive control system is made according to the Nyquist criterion. The stability of the drive system of the road printer is determined by the roots λ of the characteristic equation. Fig. 5 shows the Nyquist Hodograph as a phase portrait. The phase portrait was obtained in two coordinates: X axis is 0.2 mm and Y axis is 2.0 mm. Studies of the drive control stepper motor determined the stability of the considered control system.
Summary

1. The new technical solution of the road printer for applying figured images on a roadbed, providing the replacement of manual painting with the automated one is proposed.

2. The results of the study of the dynamic processes of a road printer have established a qualitative picture of the road printer drive phase portrait and the degree of stability of the system according to the Nyquist criterion.

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