Speed Control of the Direct Current Servomotor and the Stepper Motor with Arduino UNO Platform

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Abstract. Servomotors are special direct current or alternating current electric machines which have an adjustable rotational speed in a wide range, in both directions and which aim at moving a mechanical system along a trajectory in a prescribed time. Servomotors are used in various applications: robotics, machine tools with numerical control, aerospace technology, medical installations and others. Stepper motors are special synchronous machines that have a different construction than the classic one and are used in precision drive systems, with open loop such as: aircraft on-board equipment, timing and recording systems, electronics, office equipment, robotics industrial, etc. This paper experiences the speed control of a direct current servomotor, type SM-S2309S, with the help of the Arduino UNO platform, which is the simplest solution for the development of electronic applications. The study experiences also speed and step control of a stepper motor, type 28BYJ-48, with the Arduino UNO platform.

1. Introduction
Actuators are special motors which are used in automatic control systems as execution elements and which are intended to transform the electrical signal received from a transducer-amplifier assembly, in the form of a control voltage, into a rotation of the shaft at a so-called angle. The mechanism that requires the ordered operation is connected to the actuator shaft.

The servomotors, refers to electric motors with powers less than 1 kW, for higher powers conventional electric motors are used, which have a better efficiency and higher time constants. Asynchronous actuators and direct current actuators are used in automatic control systems.

Through a modified construction and a suitable wiring diagram, synchronous motors can fulfil the role of actuators. Actuators must meet the following special conditions: speed control within wide limits; linear adjustment and mechanical characteristics; stability and operational safety for the entire speed range; absence of self-starting; high value starting torque; high overload capacity; low control power; high response speed.

DC actuators have the following characteristics: speed regulation within very wide limits by means of a relatively simple electronic control part; adjustment and linear mechanical characteristics in the case of induced control; high starting torque; high overload capacity; small specific size and weight, etc. Their use is restricted by the presence of the collector.

DC servomotors are used to obtain partial rotations (unlike direct current motors), stable and controlled, for performing small amplitude but high precision operations: closing-opening mechanism
actuation, sensor positioning, etc. Usually, they cannot rotate 360°, but only at 90° to the right and left, compared to the initial position (they go through a maximum angle of 180°).

Asynchronous actuators remove the disadvantages of DC servomotors related to the brush collector system, but also have a number of disadvantages related to: efficiency, power factor, weight and more complicated control procedures than the DC actuator.

The stepper motor belongs to the category of special synchronous machines, which transform the numerical information into a mechanical movement, establishing a unique direct correspondence between the received information and the angular displacement. The stepper motor converts a pulse train applied to the stator coils mounted around the apparent poles, in a stepwise motion of the rotor.

Stepper motors differ from direct current and alternating current motors in that they are pulse-controlled and move step by step, with the possibility of precise rotor positioning. The stator is built with apparent poles, on each pole is placed an excitation winding, each fed independently of an electronic control system. The rotor is made of magnetic steel sheets and has a very large number of teeth. The higher the number of teeth, the better the resolution of the rotor displacement (the lower the angular displacement between two successive steps). The supply frequency of the coils and the sequence of pulses determine the speed and direction of rotation of the motor.

To increase the movement accuracy of the stepper motor, the soles of the stator poles are often notched. In this case the motor takes a much finer step, corresponding to the movement of a rotor tooth between two successive stator teeth of the same pole.

There are several constructive variants of stepper motors: with variable reluctance, with permanent magnets, or hybrids. In order to avoid the magnetic couplings between the different phases, stepper motors with several stators (multi stack) are built; In this case each phase has its own independent magnetic circuit.

Stepper motor performance is expressed by: the size of the reactive timing torque (on which the angular position error depends) and the response speed (the time it takes to perform a step); the degree of damping of the mechanical oscillations of the engine when switching from one position to another; possible frequency of switching without losing any step; operational safety. Increasing the synchronizing torque and limiting the mechanical oscillations are obtained by using permanent magnets or by providing damping bars on the rotor.

The supply is not continuous and the magnetic flux through the poles and the housing is variable, as a result the magnetic circuit must be made of sheet metal.

Through the power supply system, which also includes the control logic, a voltage or current is applied for each phase that corresponds to a well-defined position of the rotor. The feeding of the phases is sequential and the phases are not fed simultaneously as in the classic machines with rotating magnetic field, the simultaneous feeding of two phases can be achieved to obtain certain performances (removing the rotor from the stable position and reducing the pitch).

The control system ensures the sequence of phase supply according to the engine operating cycle. At high frequencies, high performance may be achieved and closed circuit operation may be required.

Advantages: low cost, simple construction, very low maintenance costs, high travel accuracy in open loop drive systems (without speed rating), fast acceleration, etc.

Disadvantages: low efficiency, vibration and acoustic noises.

Use: in precision open loop drive systems (industrial robotics, machine tools, electronics, computing, timing and recording systems, so on).

2. Equations of operation for DC servomotors
The rotation speed is adjusted by the variation of the armature voltage or by the variation of the excitation current.

2.1. Induced Adjustment by induced
In this case the excitation current is constant and the excitation can be performed with permanent magnets. The wiring diagram is shown in figure 1.
The equations that describe the operation of a DC motor with separate excitation are:

\[ U_E = R_E \cdot I_E \]
\[ U_A = R_A \cdot I_A + C \cdot \omega \cdot U_E \]
\[ M = C \cdot U_E \cdot I_A \]  \hspace{1cm} (1)

\( C \) - being a constant.

Entering the relative sizes \( \lambda, v, m \), where:

\[ \lambda = \frac{U_A}{U_E} \] - is called the signal coefficient;

\[ v = \frac{\Omega}{\Omega_0}, \ (\Omega_0 \ - \ \text{angular idle speed, } \omega_0 = p \cdot \Omega_0 ); \]

\[ m = \frac{M}{M_{sc}}, \ \text{with } M_{sc} = C \cdot \frac{U_A}{R_A} \] for \( \lambda = 1 \), the short-circuit torque is obtained from the relations (1) in relative units, the equation of the mechanical characteristic and the equation of the adjustment characteristic:

\[ m = \lambda - v \] \hspace{1cm} (2)
\[ v = \lambda - m \] \hspace{1cm} (3)

Mechanical power results from the equation:

\[ P_m = P_A - R_A \cdot I_A^2 \] \hspace{1cm} (4)

From (1), the control current is deduced, using the relative quantities:

\[ I_A = \frac{U_E}{R_A} \left( \lambda - v \right) \] \hspace{1cm} (5)

It is finally obtained:

\[ P_m = \frac{U_E^2}{R_A} \left( \lambda \cdot v - v^2 \right) \] \hspace{1cm} (6)

which in relative units becomes:

\[ p_m = \lambda \cdot v - v^2 \] \hspace{1cm} (7)
The maximum power, \( p_{\text{max}} = \frac{1}{4} \lambda^2 \), is obtained for the relative speed equal to half the value of the signal coefficient \( v = \frac{1}{2} \lambda \).

2.2. Excitation adjustment
This process requires less control than induced control, but the control characteristics are non-linear. The method is characterized by constant induced voltage \( U_A = \text{const} \). The adjustment coefficient is defined by the ratio:

\[
\lambda = \frac{U_E}{U_A}
\]  

(8)

Identical to the previous deductions, for the mechanical characteristic, in relative units, the expression is obtained:

\[
m = \lambda - v \cdot \lambda^2
\]  

(9)

And for the adjustment feature:

\[
v = \frac{\lambda - m}{\lambda^2}
\]  

(10)

The overall mechanical power is calculated as in the previous case, obtaining:

\[
p_m = \lambda \cdot v - v^2 \cdot \lambda^2
\]  

(11)

In relations (9) and (11), the torque and the reference power are given by the expressions:

\[
M_{\text{ref}} = C \cdot \lambda \cdot U_A \cdot I_A; P_{\text{ref}} = U_A^2 / R_A.
\]

3. Characteristics of the Stepper Motors

3.1. The step angle (motor step) is the angle of rotation of the rotor, corresponding to a control pulse, which is calculated by the relation:

\[
\alpha_p = \frac{360^\circ}{2 \cdot p_s \cdot p_r}
\]  

(12)

Where: \( \alpha_p \) represents the value of the step angle; \( p_s \) - number of stator pole pairs; \( p_r \) - number of stator pole pairs

3.2. The tough torque
At start-up, when the motor is powered, a torque of a certain value is required to rotate the motor rotor step by step, this torque is known as the resistant torque. When a torque higher than the strong torque is applied, the rotor will rotate continuously. Normally, the torque is higher than the working torque and acts as a powerful brake to keep the engine load still.

Due to the permanent magnetization, the stepper motor with permanent magnet and the hybrid stepper motor, have a braking torque even when the stator windings are not supplied. This torque is called the retaining torque.

3.3. The working torque
It is defined as the derivative of magnetic energy as a function of the angle of rotation of the rotor, at a constant excitation current:
\[ M_i = -\left( \frac{dW_m}{d\alpha_p} \right)_{\alpha_p = \text{const}} \]  

(13)

3.4. The limit torques

In permanent mode of operation, a quasi-stationary critical torque is defined as the maximum value at which the resistive torque can be increased at a given control frequency, without causing the motor to go out of sync (loss of steps). This torque is inversely proportional to the working frequency.

At starting the critical starting torque is defined (the maximum value of the resistive torque at which the motor can start at the given frequency without loss of steps. Similarly, the critical stopping and reversing torques are defined in the control windings as well as inertia of the drive system.

3.5. The limit frequency

The limit load characteristic and the dynamic limit characteristics (start, stop and reverse) are established by taking a given control frequency as a reference. This defines the limit torques. If a given strong torque is taken as a reference, the limit (critical) frequencies for static and dynamic operation (start, stop, reversal) can be similarly defined.

4. Speed control of direct current servomotor with Arduino UNO platform

From a hardware point of view, Arduino UNO is a development board based on a microcontroller from the AVR family (namely ATmega328P), it has six (6) analog inputs, fourteen (14) digital inputs / output pins, of which six (6) can be used as PWM outputs, a 20 MHz quartz oscillator, a USB connection, a power plug and a reset button. The development board Arduino UNO, will connect via USB cable to a PC.

4.1. Components of the speed control circuit

4.1.1. The microcontroller

It contains a processing unit and other peripherals that have the role of controlling electronic circuits. It is of the ATmega328P type and has the following characteristics: frequency 20 MHz; supply voltage: 1.8 - 5.5 V; number of pins: 28; number of input / output pins: 23; analog / digital conversion channels: 8; 8-bit timers: 2; 16-bit timers: 1; SRAM memory: 2 kB; EEPROM memory: 1 kB; Flash memory: 32 kB; write / read cycle: 10000 Flash / 100000 EEPROM; power consumption: 0.2 mA operation; stand-by 0.1 μA.

4.1.2. DC actuator

The actuator is of type SM-S2309S and has the following technical characteristics (taken from the manufacturer's data sheet): Modulation - analog; Torque: 1.00 kg-cm (4.8 V); 1.20 kg-cm (6 V); speed: 0.12 sec/60° (4.8 V); 0.10 sec/60° (6 V); rotation range: 180°; gear type: plastic; rotation/support: bushing.

The actuator consists of a direct current motor, a potentiometer driven by the motor shaft, which measures the angle at which it rotates, a circuit which compares the signal from the potentiometer with the command received from the user (via a control circuit - Arduino UNO board) and a gear mechanism, which reduces engine speed but increases torque.

If the actuator is commanded to be positioned at a certain angle, but the cause of the inertia will rotate more than desired, the control circuit inside the actuator will detect this problem by means of the potentiometer which measures its position and will quickly correct the error. If an attempt is made to forcibly change the position in which the actuator has been set, it will resist. There are three wires for the connection: GND, 5 V and a control wire, which will be connected to a PWM pin, on the Arduino UNO development board. The servomotor terminals comply with the following color code: yellow - control; black - GND, red - power supply.
4.1.3. **The potentiometer**
It is a three-terminal resistor with a sliding or rotating contact, which forms an adjustable voltage divider. When using only two terminals, it acts as a variable resistor or rheostat.

4.1.4. **The electric capacitor**
One can also place a capacitor across the power and ground going into the potentiometer. When a servo motor starts to move, it draws more current than if it were already in motion and this will cause a dip in the voltage on the breadboard. By placing a 100 μF capacitor across power and ground right next to the male headers as shown in Figure 1, one can smooth out any voltage changes that may occur. On can also place a capacitor across the power and ground going into the potentiometer.

4.1.5. **The breadboard** is an experimental panel that allows the easy connections of an electronic circuit without the use of soldering.

4.1.6. **The connecting wires**
Figure 2 shows the electrical connection diagram of the components for testing the servomotor.

![Figure 2. Wiring diagram of the components for controlling the speed direction of the actuator used.](image)

4.2. **The software program**
The easiest way to control servo motors is by using the Servo.h library, which allows you to declare up to eight (8) Servo objects and use the functions related to these objects: attach (pin) to indicate the object with which pin communicate or write (position) to directly control the position of the servomotor (on the pin indicated by the attach (method) a PWM (Pulse Width Modulation) pulse will be generated that controls the servomotor). Arduino IDE is the software program on your PC, in which you write the code that will be loaded on the Arduino UNO development board.

4.3. **The experiment performed**
The following figures show the assemblies made in the experiment.
5. The stepper motor control

Optimal choice of a stepper motor for a particular application requires a thorough understanding of the characteristics of the motor and its control circuits. The maximum benefit of a stepper motor can only be obtained if it is correctly ordered; it requires a direct current source, an electronic switch, and a controlled pulse generator (numerical information). The control pulses can be obtained from an own pulse generator or from a numerical process computer, by means of a digital filter (for calibrating the distance between the pulses). The control can be performed in open circuit or in closed circuit. Open circuit control generally requires the use of special acceleration-braking techniques so that no loss of steps occurs.

To avoid malfunction, unwanted behavior, complicated electronic schemes, the control of motors is done with the help of specialized motor drivers.
6. Speed and step control of a stepper motor with Arduino UNO platform

The Arduino UNO platform is described in detail at the section 4.

6.1. The stepper motor

The stepper motor is of type 28BYJ-48 and has the following technical characteristics (taken from the manufacturer's data sheet): supply voltage 5 V DC; Number of Phase 4; Speed Variation Ratio 1/64; Stride Angle $5.6250 / 64$; Frequency $100$Hz; DC resistance $50\Omega \pm 7\%$ (250 C); Idle In-traction Frequency $> 600$ Hz; Idle Out-traction Frequency $> 1000$ Hz; In-traction Torque $> 34.3$ mN·m (120 Hz).

6.2. The ULN 2003 motor driver

It contains several Darlington transistors, so that it can transmit commands on each motor winding. A Darlington transistor consists of two ordinary transistors connected in series, in order to be able to control a current as high as possible, with a control current as low as possible.

6.3. The software program

The stepper motors can be most easily controlled by using the Stepper.h library which allows the declaration of up to eight (8) objects of the Stepper.h type and the use of the functions related to these objects: attach (pin) to indicate the object with which the pin communicate or write (position) to directly control the position of the stepper motor. Arduino IDE is the software program on your PC, in which you write the code that will be loaded on the Arduino UNO development board.

6.4. The experiment performed

The following figures show the assemblies made in the experiment.

**Figure 6.** Connecting the stepper motor with the ULN 2003 driver to the Arduino UNO platform.

**Figure 7.** Connecting the stepper motor with the ULN 2003 driver to the Arduino UNO platform and connecting to the PC.

**Figure 8.** Step-by-step engine speed analyzed control software.
7. Conclusions

The program (Figure 5) controls the servomotor to obtain movements from 0 to 135 degrees in both directions. The two programs control the direction of speed (clockwise and counter clockwise, Figure 8 and Figure 9) and the steps of the stepper motor, until it performs a complete rotation.

Stepper motors can perform precise movements, just like servomotors, so in many applications you can use any of them. Stepper motors can move with good accuracy and generally have high torque. An advantage of these motors is that when they are stationary, they have maximum torque, unlike other motors (direct current), also their speed can be precisely controlled. The main disadvantage of servomotors is that stepper motors do not have a feedback loop. Many applications require a positioning switch or encoder to provide information about their position. In combination with such systems, stepper motors can achieve very good performance. Another disadvantage of stepper motors is the low energy efficiency (consumption does not depend on the load they consume maximum power when standing still). Stepper motors have a robust construction, withstand heavy loads, mechanical shocks and can operate at high temperatures.

Arduino is the simplest solution to develop electronic applications. It is an easy way to use the platform. Arduino offers many examples of projects, explanations and tutorials. The microcontroller used is initially programmed using additional hardware devices called programmers. To eliminate the need for such a device, this microcontroller writes boot loader, a small software program that takes the instructions (program code) through the serial interface and writes them to a non-volatile memory area (FLASH), from where the microcontroller will interpret them and run. Another method is needed to convert from USB to serial, in order to program the microcontroller used, through the USB port of the PC.

8. References

[1] Saboiu S P 2018 Îndrumător laborator microcontrolere ARDUINO (Cluj Napoca: UT Press) pp 50–54
[2] Rebega A and Florea B F 2016 Introducere în Arduino (București: Optimus Digital - Magazin de Electronică și Robotică) chapter 16 pp 65–70
[3] Craiu O and Tudorache T 2015 Mașini și Acționări Electrice (București: Politehnica Press) chapter 5 pp 202-209
[4] Fitzerald S and Shiloh M 2012 Arduino Projects Book (Italy Torino) chapter 5 pp 54–69
[5] Galan N 2011 Mașini Electrice (București: Ed. Academiei Române) chapter 8 pp 828–871
[6] https://www.makerguides.com
[7] http://www.arduino.cc/en/Tutorial/Sweep