University of Calabria

College of Engineering

Report for the course of

Industrial automation

Title: Modeling of the cut of a laser cutting machine.

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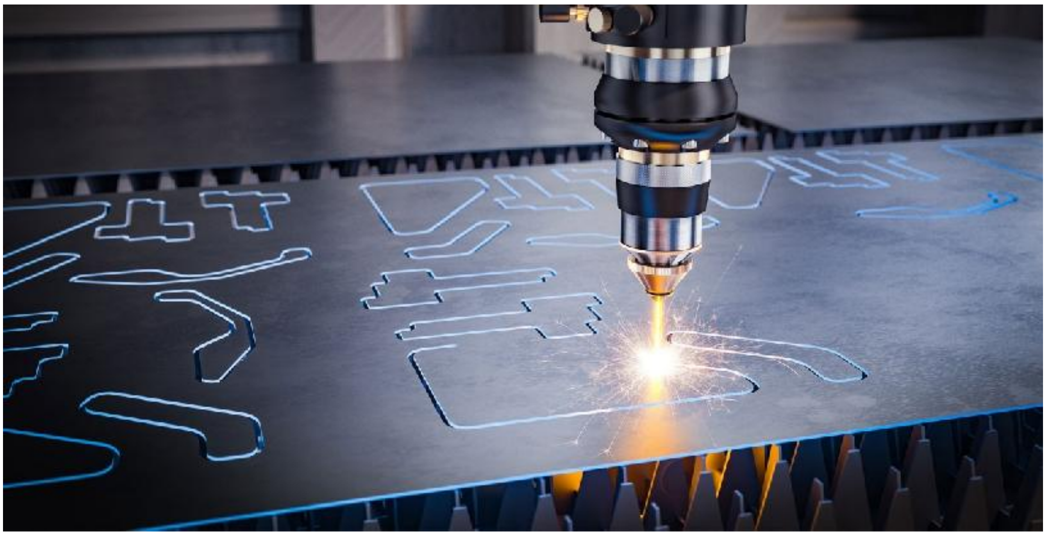
Brief Relate:

Laser cutting is a technique used to cut sheet metal parts characterized in that its energy source is a laser that concentrates light on the work surface. In order to evacuate the cut material, it is necessary to supply a pressurized gas such as oxygen, nitrogen or argon. It is especially suitable for pre-cutting and for trimming excess material and can develop complicated contours in the pieces. Among the main advantages of this type of part manufacturing, it can be mentioned that it is not necessary to have cutting dies and it allows for silhouette adjustments. Also, among its advantages it can be mentioned that the drive is robotized to be able to keep the distance between the electrode and the outer surface of the piece constant.



To highlight as unfavorable points, it can be mentioned that this procedure requires a high investment in machinery and the more heat conductive the material is, the more difficult it will be to cut. The laser thermally affects the metal but if the graduation is correct it does not leave burrs. Workpieces are preferred opaque and not polished because they reflect less. The most common thicknesses vary between 0.5 and 6 mm for steel and aluminum. The most common powers for this method are between 3000 and 5000 W.

Structure:

The system referred to is composed of two equal motors, one to generate movement in the x axis and the other to generate movement in the y axis, making this machine can move in 2 dimensions.

Fig.1

Tasks to perform:

The system by driving the two DC motors must perform the cut on a plate that would be the work area. First you should make the cut of a square with a side of 2 m for which the Cartesian system is used and then you should cut a circumference of radius 0.75m using the polar system.

1. System rest position (0,0)
2. Move to the starting point where the square cut will begin (-0.5, 1.5)
3. Start cutting clockwise at the points (-0.5,0), (- 2.5,0), (- 2.5,1.5), (- 0.5,1.5)
4. After finishing the cut of the square, go to point (3.55,2.55) to start cutting the radius circumference 0.75m.

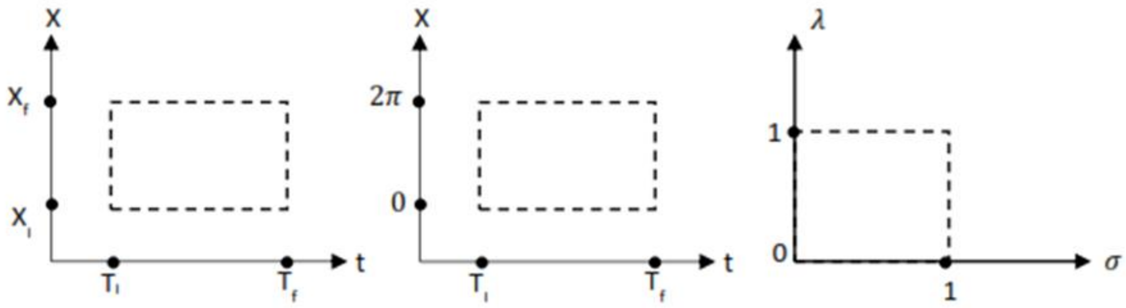
Path generation:

The movement of the laser has been described by using an interpolation polynomial of two adjacent fifth degree points, which generates the reference.

The chosen interpolation polynomial is:

$$x(t) = a_0 t^m + a_1 t^{m-1} + \cdots + a_m t^m$$

Then we proceed with the normalization of the trajectory:



$\lambda = \frac{X - X_i}{X_f - X_i}$ $\quad$ $\lambda = \frac{\theta - \theta_i}{\theta_f - \theta_i}$ $\quad$ $\sigma = \frac{t - T_i}{T_f - T_i}$

$X = X_i - \lambda(X_f - X_i)$ $\quad$ $\theta = \theta_i - \lambda(\theta_f - \theta_i)$ $\quad$ $\sigma = \sigma_i - \lambda(\sigma_f - \sigma_i)$

$(t, x) \leftrightarrow (\sigma, \lambda)$: The property in space (t, x) is completely analogous to that of space (σ, λ)

$x(t) \leftrightarrow \lambda(\sigma)$: The property of the function $x(t)$ is equivalent to the property $\lambda(\sigma)$

The polynomial can be written as follows:

$$\lambda(\sigma) = a\sigma^m + a_1\sigma^{m-1} + \cdots + a_m\sigma^m$$

The fifth-degree polynomial would be as follows:

$$\lambda(\sigma) = a\sigma^5 + a_1\sigma^4 + a_2\sigma^3 + a_3\sigma^2 + a_4\sigma + a_5$$

With the regulated path, the following conditions apply:

$$T_i = 0 \; y \; T_f = 1 \leftrightarrow V(T_i) = 0 \; y \; V\left(T_f\right) = 0$$

Values of position, velocity and acceleration when calculating a_n:

$\lambda(0) = 0$ $\quad$ $\dot{\lambda}(0) = 0$ $\quad$ $\ddot{\lambda}(0) = 0$

$\lambda(1) = 1$ $\quad$ $\dot{\lambda}(1) = 0$ $\quad$ $\ddot{\lambda}(1) = 0$

The system of linear equations is obtained:

$\lambda(0) = a_5 = 0$

$\dot{\lambda}(0) = a_4 = 0$

$\ddot{\lambda}(0) = a_3 = 0$

$\lambda(1) = a_0 + a_1 + a_2 = 1$

$\dot{\lambda}(1) = 5a_0 + 4a_1 + 3a_2 = 0$

$\ddot{\lambda}(1) = 20a_0 + 12a_1 + 6a_2 = 0$

The values are obtained:

$a_0 = 6, a_1 = -15, a_2 = 10, a_3 = 0, a_4 = 0$

The polynomial is as follows:

$\lambda(\sigma) = 6\sigma^5 - 15\sigma^4 + 10\sigma^3$

Equation to calculate a straight path:

$X = X_i - \lambda(\sigma)(X_f - X_i)$

$Y = Y_i - \lambda(\sigma)(Y_f - Y_i)$

Equation to calculate a circumference:

$X(\theta) = X_c + R \quad (\theta)$

$Y(\theta) = Y_c + R \quad (\theta)$

DC motor control:

The direct current motor, also called direct current motor, DC motor or CC motor, is a machine that converts electrical energy into mechanical energy, causing a rotary movement, thanks to the action of a magnetic field. The basic operating principle of a DC motor is explained from the case of a loop of conductive material immersed in a magnetic field, to which a potential difference (or voltage) is applied between its ends, so that a current circulates through it i. It is possible to control the speed and torque of these motors using direct current motor control techniques.

Electrical diagram of the DC motor:

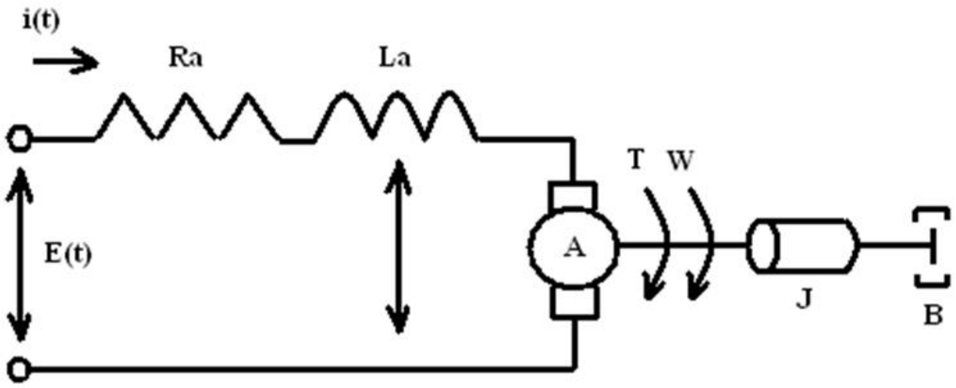


Fig.2

- Electric model:

$$L_a \frac{di_a}{d} = V_a - R_a i_a - K_m \omega$$

- Mechanical model:

$$J\frac{d}{d} = K_m i_a - b \quad - \tau_r$$

$$\frac{d\theta}{d} = \omega$$

Where:

L_a	armor inductance
R_a	torque coefficient and electromotive force
J	armor resistance
b	inertia
i_a	friction coefficient
Ω	rotor speed
Θ	rotor position
V_a	income voltage
τ_r	disturbance

- The input-output transfer function of the motor would be:

$$G(s) = \frac{\theta(s)}{V_a} = \frac{K_m}{(SL_a + R_a)(J{:} + b) + K^2{}_m}$$

- The block diagram of the DC motor is as follows:

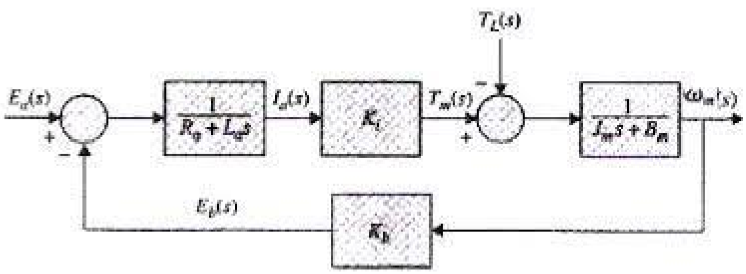


Fig.4

The scheme is mainly made up of two blocks:

- The electrical part that has a voltage as an input and a torque as an output.
- The mechanical part that has torque as input and speed as output.

The electrical subsystem of the motor is characterized by a first order polynomial having a real pole equal to $P_e = -\frac{R_a}{L_a}$ the named electrical pole and the mechanical subsystem that has a characteristic equation also of the first order characterized by a pole $P_m = -\frac{b}{J}$ that is called mechanical pole.

- Specifications of the used motor:

The system uses 2 identical DC motors with the following characteristics:

R_a	L_a	J	b	K
1Ω	5.0 mH	0.05Kgm^2	2*10^{-3}Nms/rad	0.56

Engine's limitations:

- $|V| \leq 75\ v$
- $|I| \leq 10A$
- Coefficient of transduction for both axes $\frac{1}{6\ \pi}\frac{r}{m}$

Simulation scheme in Simulink:

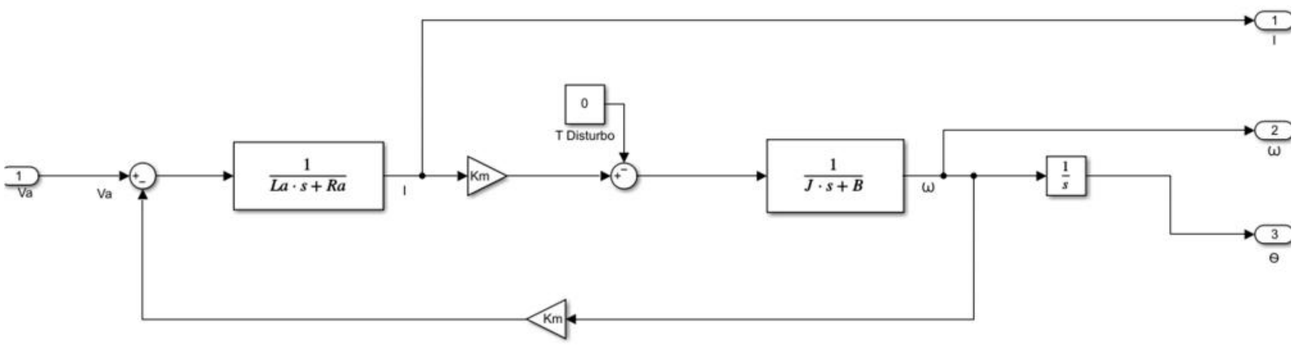
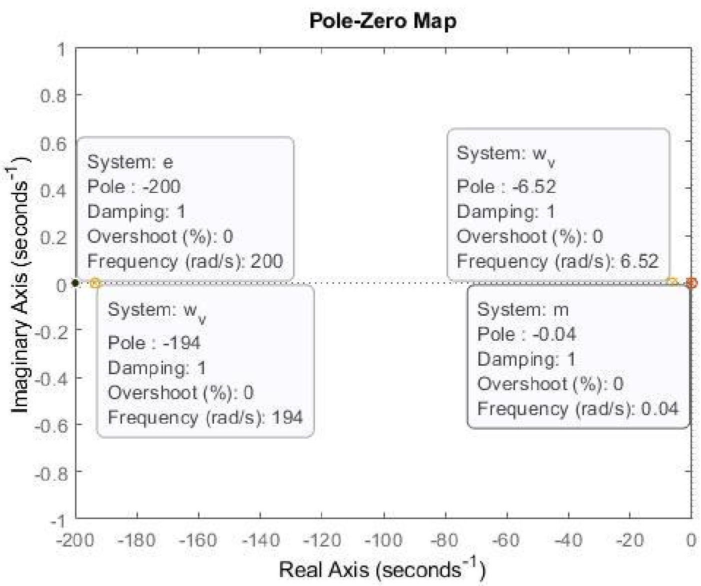


Fig.5

Zero-pole diagram:



Fig,6

In the figure you can see the electric pole $P_e = -200$ and the mechanical pole $P_m = -0.04$. The poles of the closed-loop system are: $P_e = -194$ and $P_m = -6.52$. The electric pole slows down and the mechanical pole increases its speed. The transients are governed by the mechanical pole.

Since the poles of the function are we can say that the system is asymptotically stable.

Control strategy used to control DC motors:

To control the torque, the speed of rotation and the supply voltage of the motor, the PID is used.

A PID controller (proportional, integral and derivative controller) is a control mechanism that through a feedback loop allows to regulate the speed, temperature, pressure and flow among other variables of a process in general. The PID controller calculates the difference between our real variable against the desired variable.

The PID control algorithm consists of three different parameters:

- proportional depends on the current error
- integral depends on past errors
- derivative is a prediction of future errors

The sum of these three actions is used to adjust the process by means of a control element, such as the position of a control valve or the power supplied to a heater.

The mathematical expression of the PID is as follows:

$$u(t) = k_p e(t) + k_i \int_{t_i}^{t_f} e(\tau) d \quad + k_d \frac{d \ \ (t)}{d}$$

Where:

u(t): control signal of the process transfer function

e(t): error between desired value and actual value

K_p: Proportonial gain

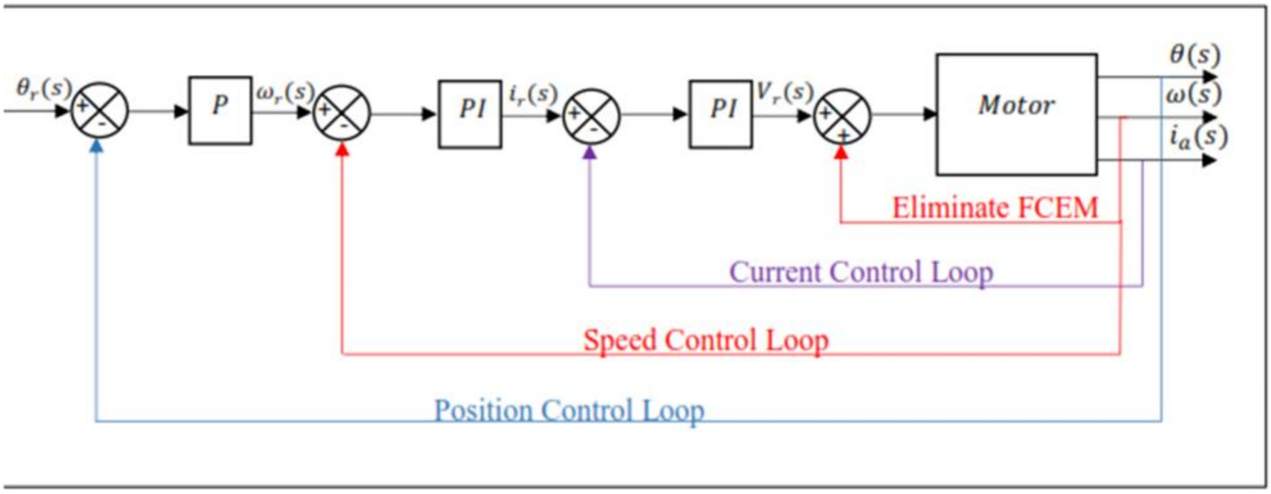
K_i: Integral action constant

K_d: Derivate action constant

The control strategy consists of compensating the back electromotive force and implementing a composite cascade structure:

- the current loop, which is the innermost of the cascade, controls the current with feedback from the armature.
- the intermediate speed loop controls the speed of the motor with feedback from the angular speed of the motor rotor.
- The position loop, which is the external one and controls the general dynamics of the motor with integrated feedback of the angular velocity of the rotor.

For a better analysis, the control system is divided into three subsystems:



Fig,7

Feedforward control:

Describes a type of system that reacts to changes in its environment, usually to maintain some specific state of the system. A system that exhibits this type of behavior responds to disturbances in a predefined way, in contrast to feedback systems.

To apply the feedforward system, the following requirements must be taken into account:

- disturbances must be measurable
- its effects on the output of the system must be known
- the time during which the disturbances affect the output must be greater than that of the system itself

The feed-forward system can respond more quickly to known and measurable types of disturbances, but hardly does so with new ones.

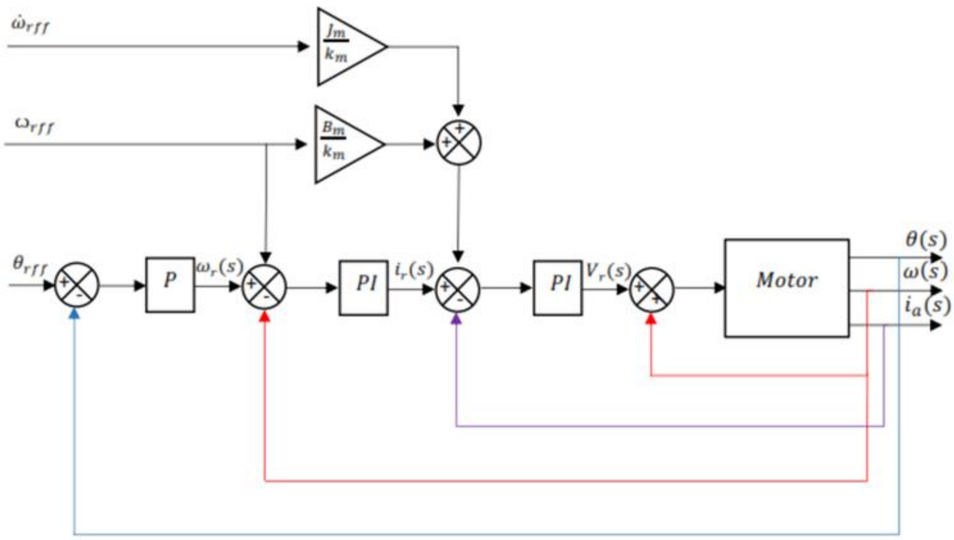


Fig.8

Calculations of the PID parameters:

- PID parameters in the current loop:
  - porportional action: $K_p = K * L_a$, $K_p = 200 * L_a$
  - integral action: $K_i = K * R_a$, $K_i = 200 * R_a$

K is chosen such that $K \approx |P_e| = 200$ the important thing is that there is feedback on the current, without modifying the tempo constant. The integral effect tends to compensate for the errors made in the measurement of R_a and L_a.

- PID parameters in the speed loop:
  - porportional action: $K_p = K * J$, $K_p = 200 * J$
  - integral action: $K_i = K * b$, $K_i = 200 * b$

K is chosen in such a way as to allow the mechanical part to be given some speed, of at least a decade, in this case $K = 25$. With this type of feedback, ignorance or eventual errors with respect to the nominal values of J and b are offset; it also reduces or eliminates the disturbing effects that are present.

- PID parameters in the position loop:
  - Only a proportional action is chosen, establishing the value of $K_p$at least 1 decade to the to the right of the velocity pole, in this case $K_p = 1$.

These values are used for both the x-axis motor and the y-axis motor.

Matlab diagrams:

Control scheme in Simulink:

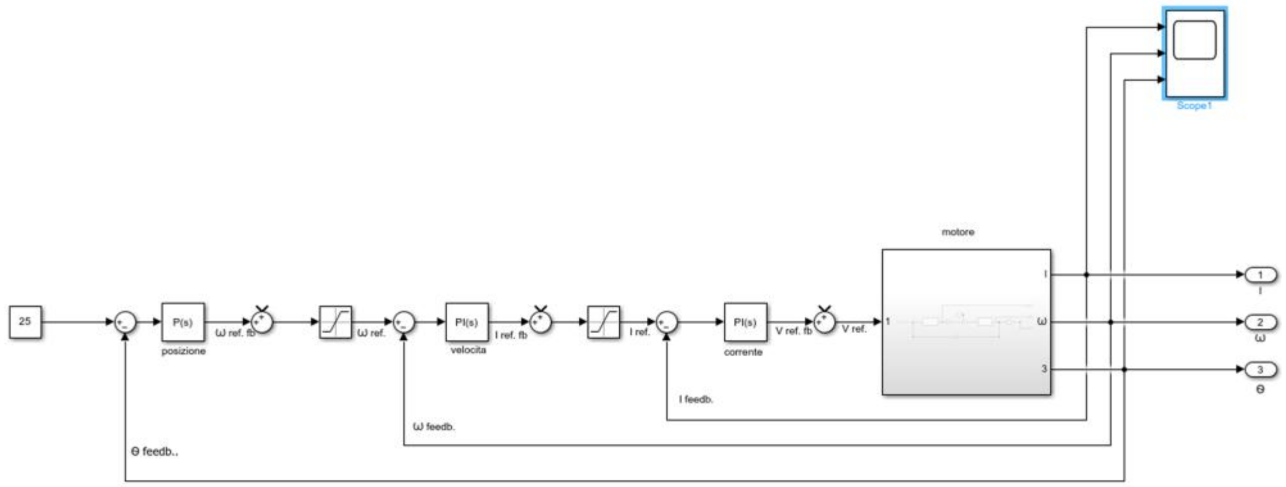


Fig.9

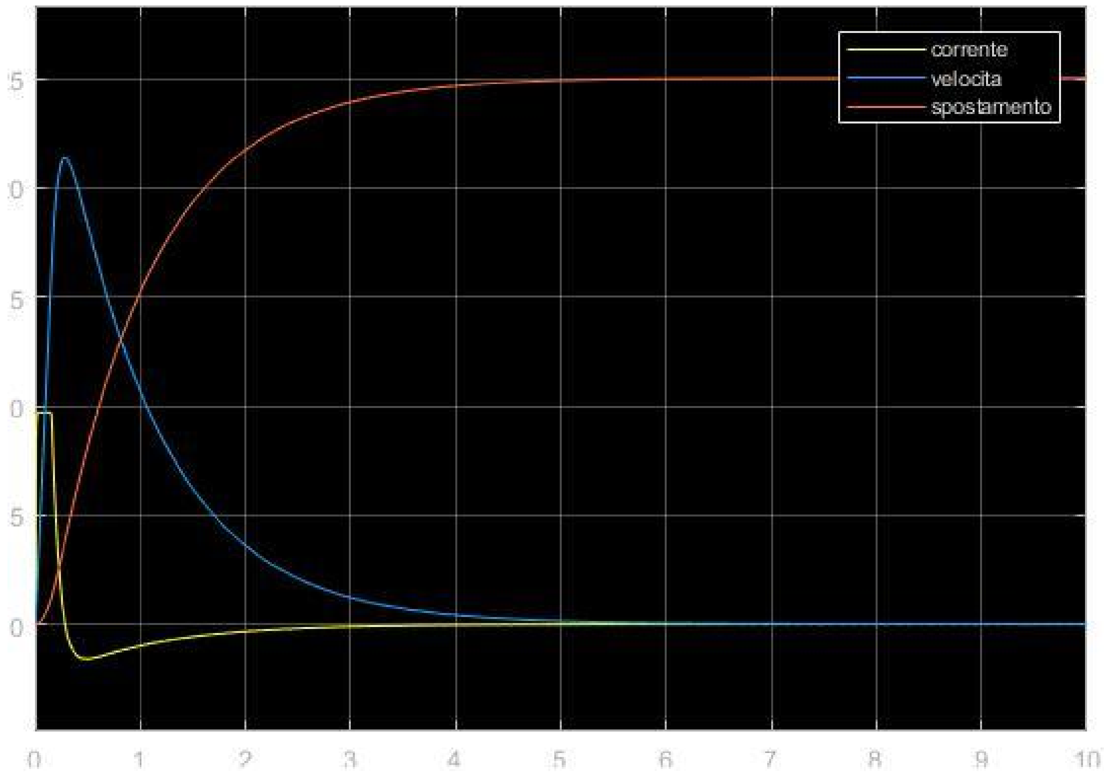


Fig.10

With a constant input equal to 25, the system in time tends to this value. So, it can be stated that the chosen parameters are correct.

Feedforward control scheme in Simulink:

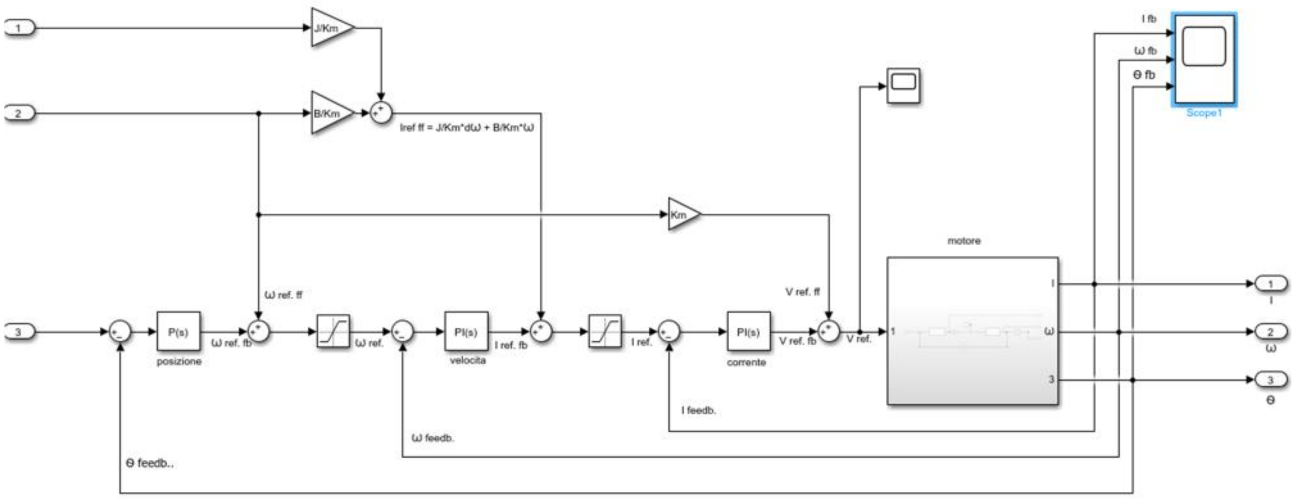


Fig.11

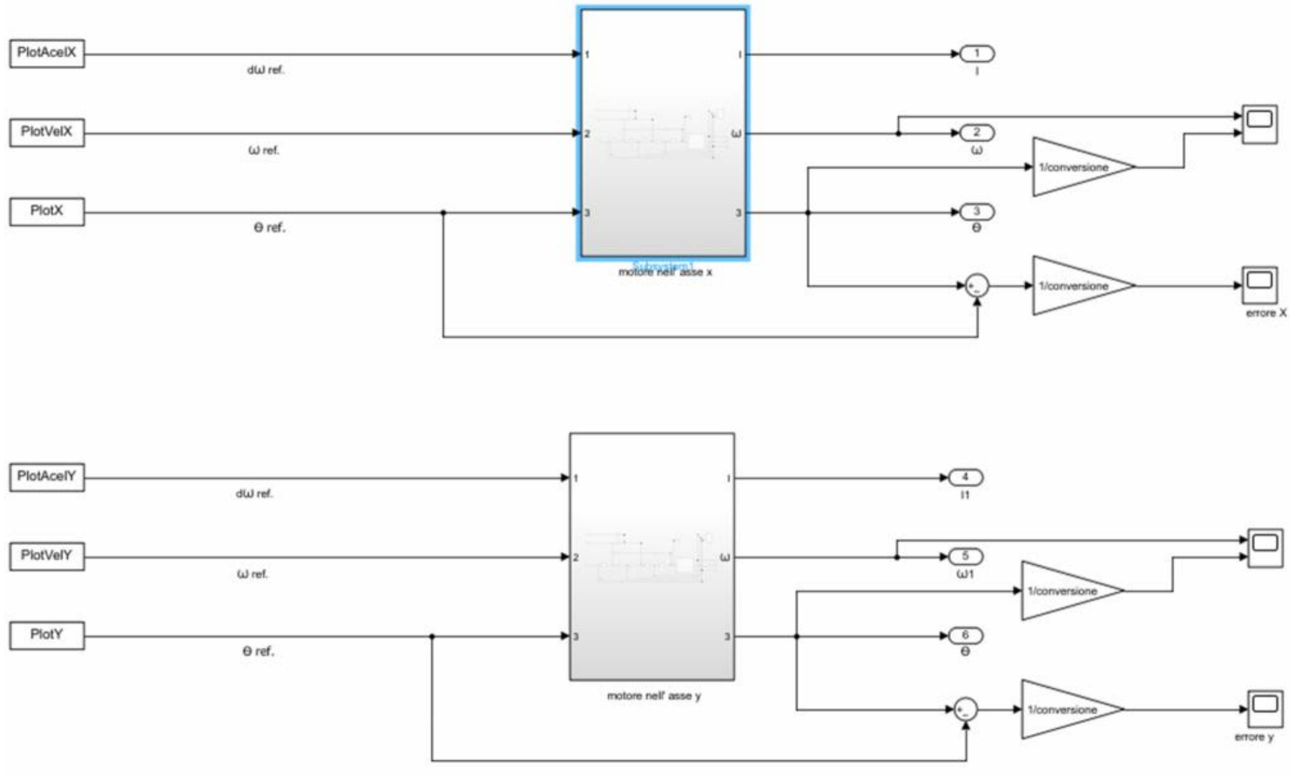


Fig.12

Position of both motors during cutting:

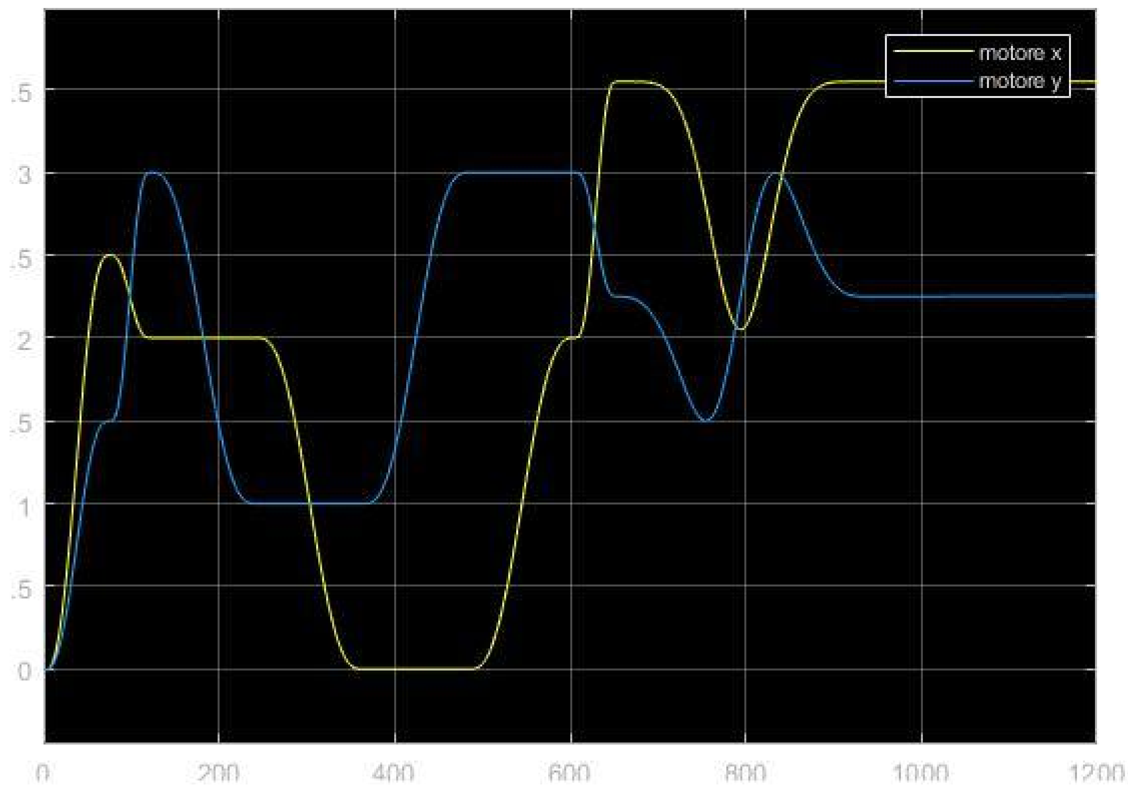


Fig.13

Parameters of the motor that controls the movement in the X axis:

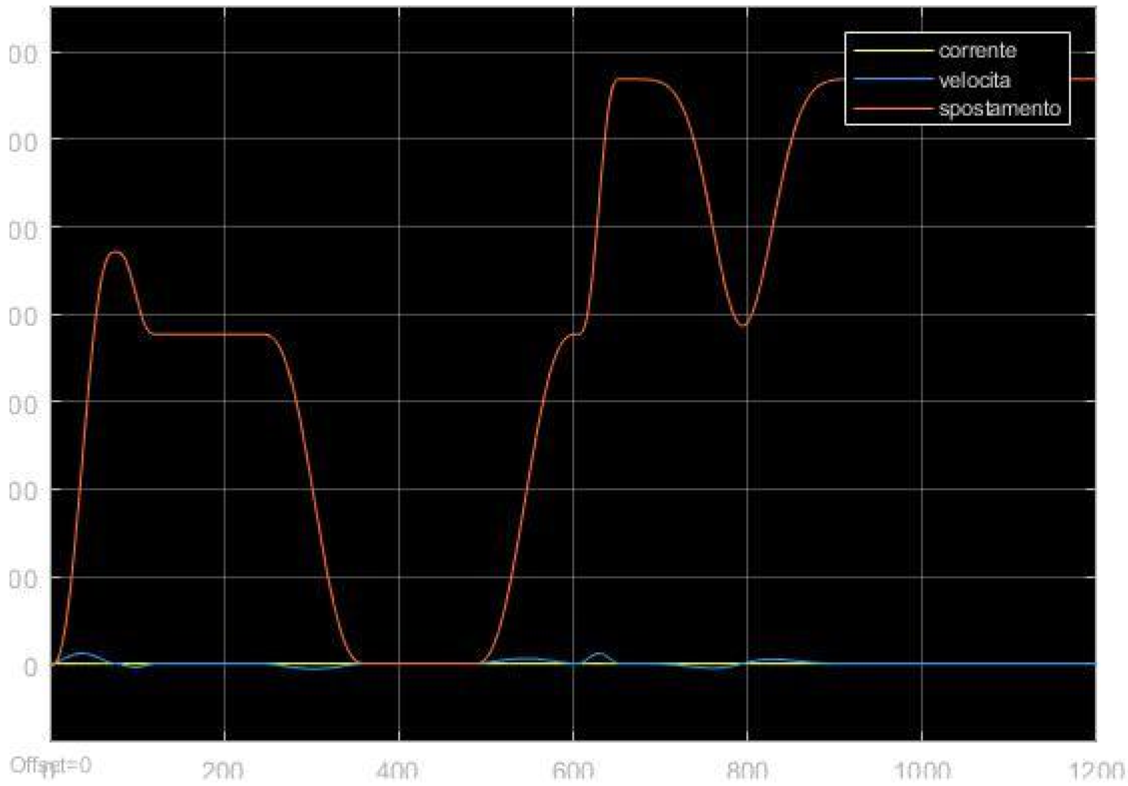


Fig.14

Parameters of the motor that controls the movement in the Y axis:

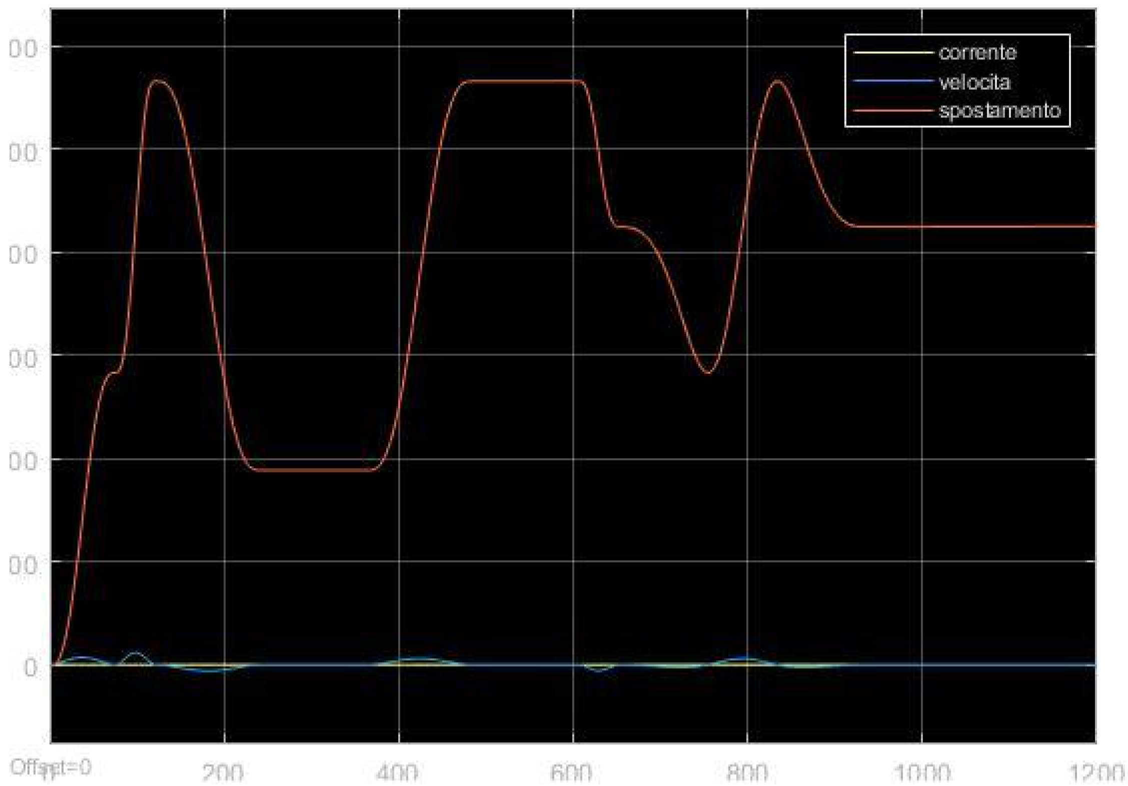


Fig.15

Error:

X axis:

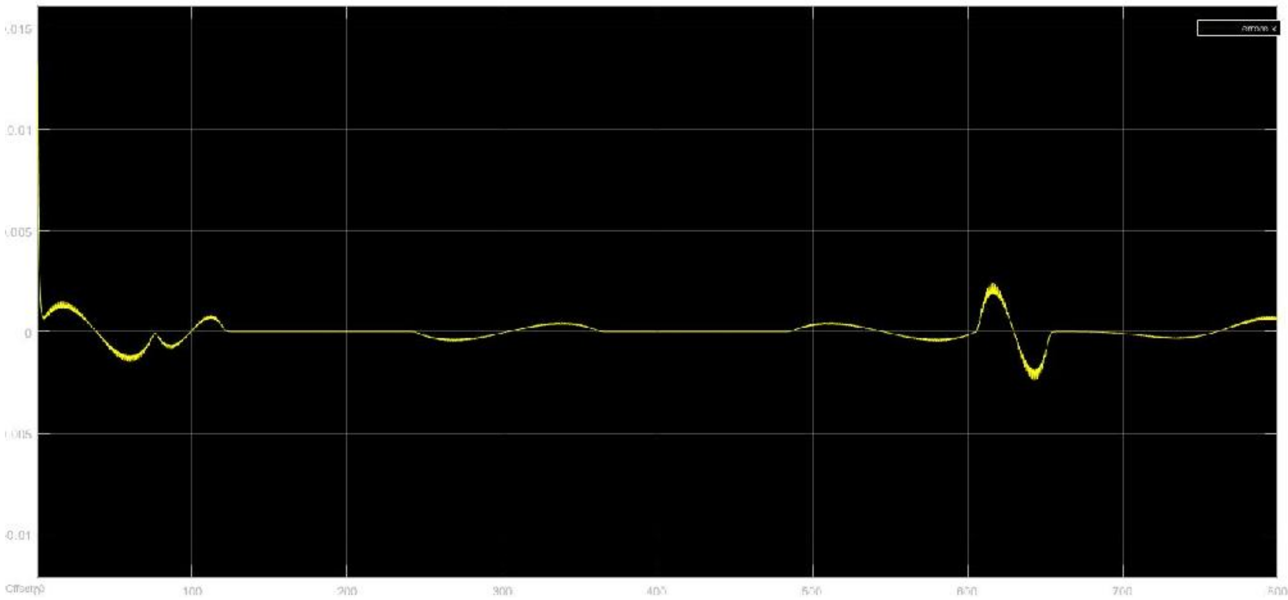


Fig.16

Y axis:

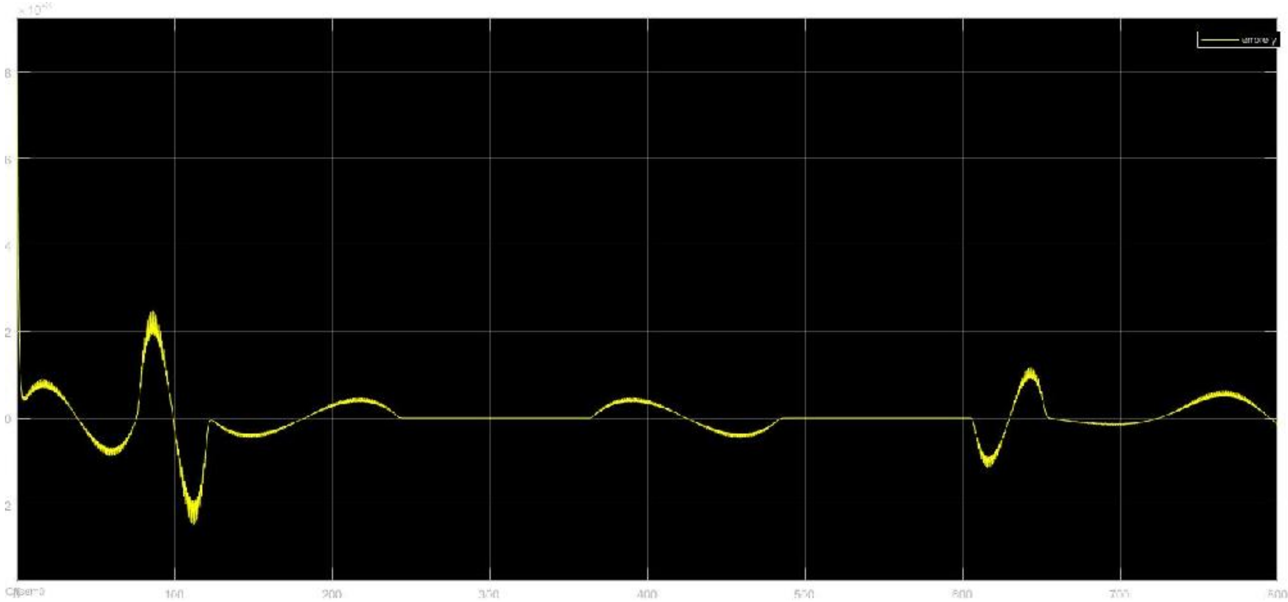


Fig.17

It can be seen in the graphs of both axes that the error remains below 2mm.

Simulation of the cut in Matlab:

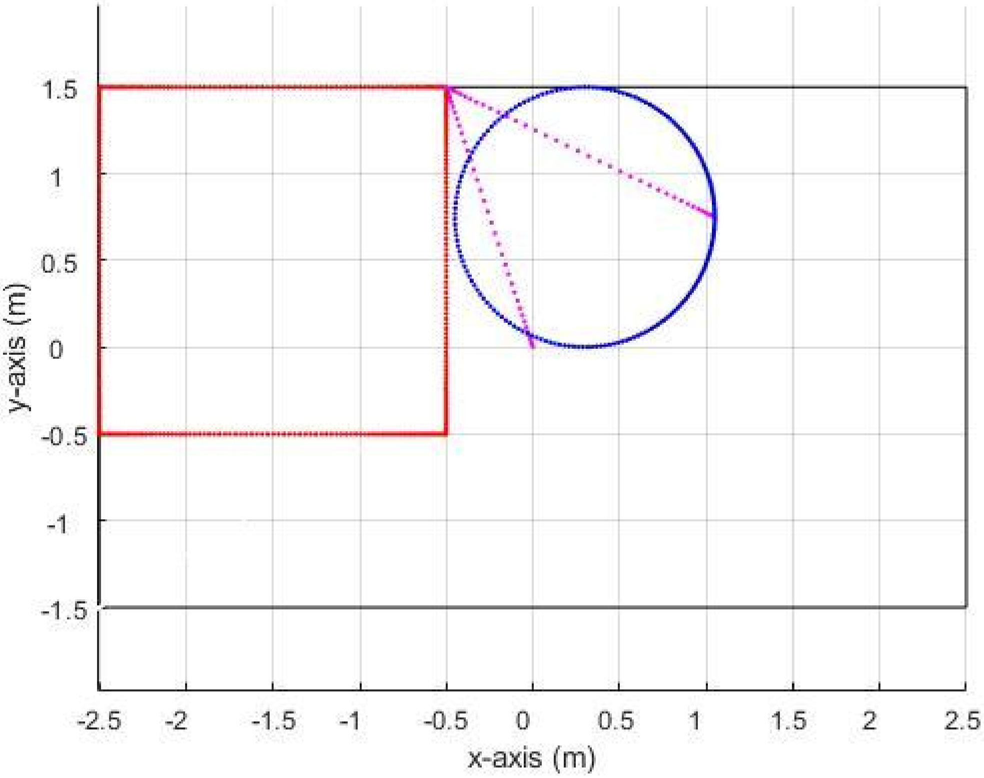


Fig.18

Conclusions:

In this work, the generation of the laser cutting path was performed using a fifth-degree polynomial. For the implementation of the control action, two identical motors are used, one to generate displacement in the x-axis and the other in the y-axis. A Feedforward control was applied to each motor and all the necessary parameters were calculated for the correct implementation of the current, position and speed control loops. The system presents an asymptotic stability and the error is within the permissible parameters.