ME2400

MEASUREMENTS, INSTRUMENTATION AND CONTROL

PROJECT 2

IDENTIFYING CLOSED LOOP TRANSFER FUNCTION AND SIMULATING A MODEL OF THE CNC MACHINE USING SIMULINK - A REPORT

Name : Ashwin Upamanyu Dev

Roll No : ME19B085

Email ID : me19b085@smail.iitm.ac.in

Submitted on: 10/06/2021 ; Submitted to: Prof. Sivasrinivasu Devadula

---

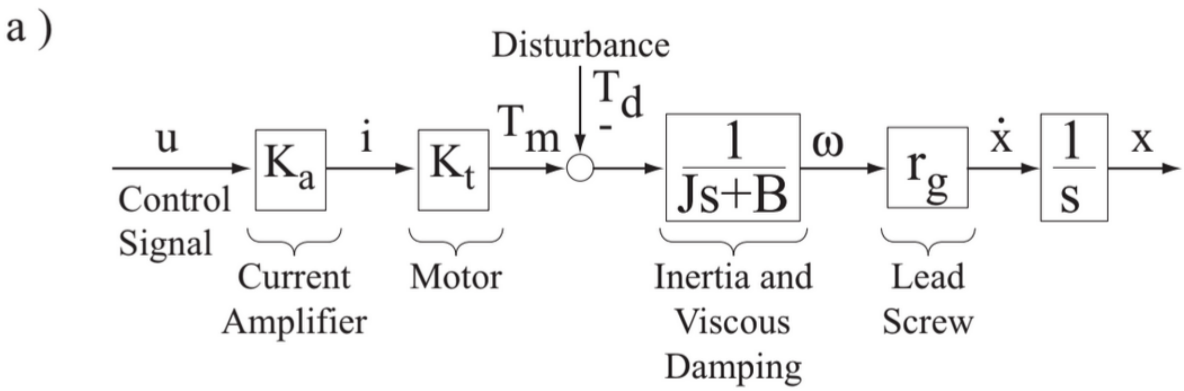
ABSTRACT : Each drive on a Commercial Numerical Controlled (CNC) machine tool is controlled with feedback controllers. Commercial CNC machines have generally closed and polished architecture. Therefore, to estimate the drive dynamics of such a machine to simulate its overall tracking and contouring performance, an identification method is necessary. This is explored in this project.

1.INTRODUCTION

In this particular project, to estimate the drive dynamics, we use P-PI (Proportional - Proportional Integral) control mode with feed forward and friction compensation. After formulating the necessary equations, we use an optimization technique - Particle Swarm Optimization (PSO) to solve the nonlinear optimization problem. This is then simulated using software, such as Simulink.

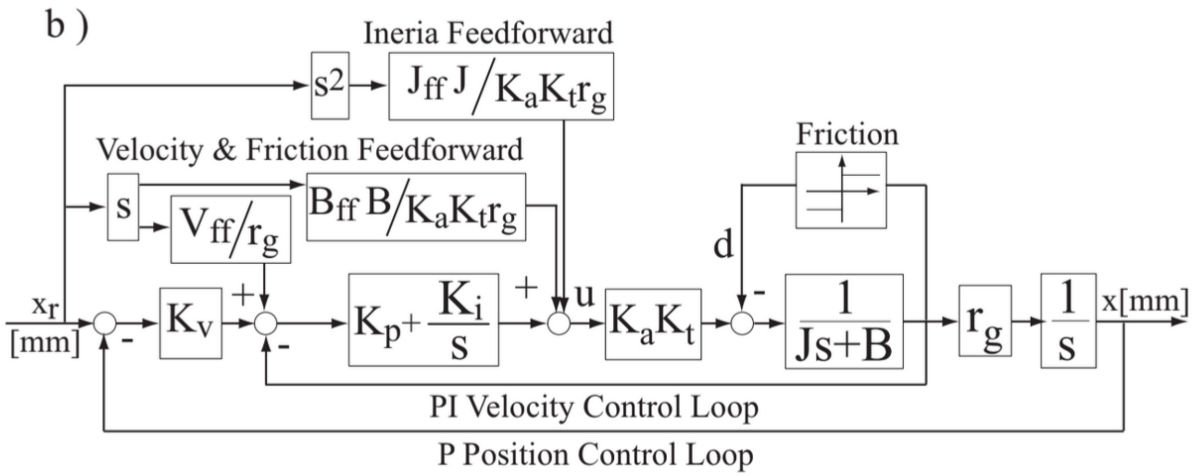
2.CLOSED LOOP FEED DRIVE DYNAMICS MODEL

The modern 5-axis CNC drive systems are generally modelled using various feedback techniques such as P, PI, PID, P-PI cascade controllers with feedforward dynamic and friction compensation.



The servo model shown above (a) considers the rigid body motion of a feed drive mechanism where J kgm^2 is the total inertia and B kgm^2 /s is the viscous damping of the axis. In this model, motor and the amplifier are assumed to operate within their linear range, where u V is the control voltage signal command to the current amplifier with a gain of K_a A/V, and the corresponding torque delivered to the drive is obtained by multiplying the current with the motor torque constant K_t Nm/A, and rg mm/rad is transmission gain of the ball-screw mechanism.

Now, coming to the commercially used CNC systems, the most widely used position control structure in commercial CNC drives is shown in the figure (b) attached below. In this scheme, the velocity loop is closed using Proportional-Integral (PI) control by adjusting the gains K_p, K_i and the position loop is closed by a proportional control (P) using K_v.



PID controllers are also used extensively, but we'll look at P-PI controllers here. In the P-PI controller scheme, the feed-forward compensation of axis dynamics is applied to widen the servo tracking bandwidth where $V_{ff} \in [0,1]$, $B_{ff} \in [0,1]$, $J_{ff} \in [0,1]$ are the respective gains used to cancel the dynamics in P-PI controller.

For the system, the closed loop transfer function between the commanded (x_r mm) and actual axis position (x mm) can be written as:

$x(s) = [(b_0s^2 + b_1s + b_2 + a_3/s)/(s^2 + a_1s + a_2 + a_3/s)]*x_r(s) - [(r_g/J)/(s^2 + a_1s + a_2 + a_3/s)]*d(s)$

Here $d(s) = sign(\dot{x})d_c$, sign() is the signum function and d_c Nm is the average Coulomb friction torque. Therefore, the equation can be written:

$$\boxed{[s^2 + a_1s + a_2 + a_3 / s]\, x(s) = [b_0s^2 + b_1s + b_2 + a_3/s]\, x_r(s) - sign(\dot{x})d_c}$$

These values of a_1, a_2, a_3, b_0, b_1, b_2, and d_c can be expressed as the model parameters as follows:

$$a_1 = \frac{B + K_aK_pK_t}{J},\ a_2 = \frac{K_aK_pK_vK_tr_g + K_aK_iK_t}{J}$$

$$a_3 = \frac{K_aK_iK_tK_vr_g}{J},$$

$$b_0 = I_{ff},\ b_1 = \frac{BB_{ff} + K_aK_pK_tV_{ff}}{J},$$

$$b_2 = \frac{K_aK_pK_vK_tr_g + K_aK_iK_tV_{ff}}{J},\ d_c = \frac{dr_g}{J}$$

3.SOLUTION

The solution to the above problem, that is the values of the parameters a_1, a_2, a_3, b_0, b_1, b_2, and d_c can be obtained using advanced optimization algorithms such as Particle Swarm Optimization (PSO) algorithm. To identify these 7 parameters, an objective function which is a linear programming problem with non-linear constraints is obtained [1].

Using the objective function and PSO algorithm, these parameters can be obtained as [1]:

Parameter	**Value**
a_1	238.4335
a_2	48421.5859
a_3	2487140.30
b_0	0
b_1	117.5424
b_2	37258.9796
b	2.6815

4.SIMULINK MODELLING

In the Simulink software, we can create the model with ease. This simulink file is provided in the folder, with the name

All of the blocks used for creating the model is listed below:

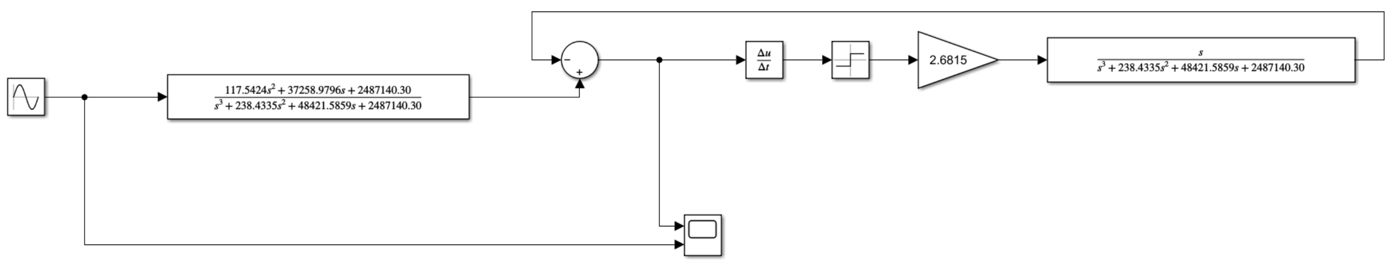
1. Input Signal
2. Transfer function
3. Sum
4. Derivative
5. Sign

6. Gain
7. Scope

These blocks are connected using arrows in the logical order as follows:

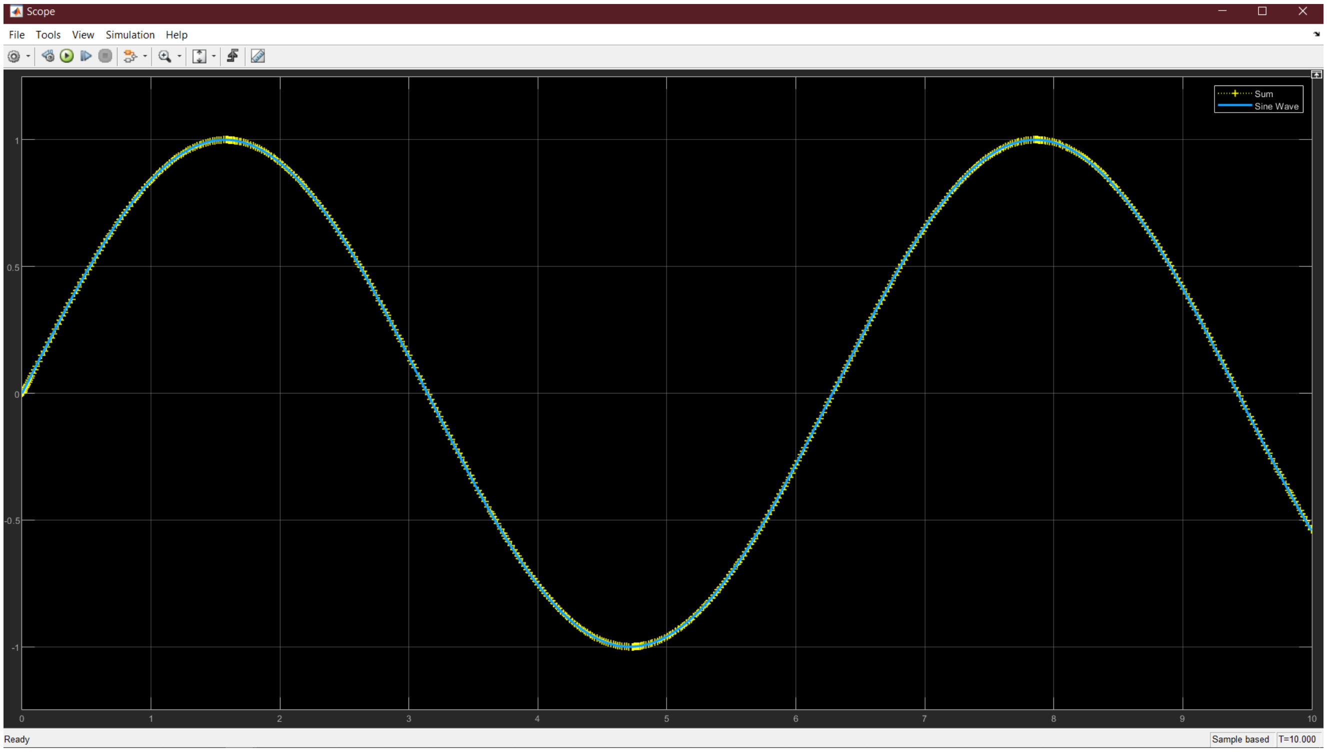
1. Input is connected to the transfer function.
2. This is connected to the sum.
3. From sum, output is obtained, which is connected to the scope to obtain the result.
4. Another route from the sum directs the output to a differentiation operator, followed by signum function and a gain (d_c). This is then followed by another transfer function, which goes to the -ve terminal of the sum block. Hence this is subtracted from the value obtained in step 1.
5. Processes 1 to 4 is repeated till we get the required value

The Simulink model is shown in the figure attached below.



A sine wave input signal is used here as the command signal. The corresponding output can be obtained from the scope. For the sine function, this is as follows:

The yellow '+' shows the output signal and the blue continuous line indicates the input signal.



5.CONCLUSION

Using Simulink to simulate the model obtained using the closed loop transfer function whose solution is obtained using PSO algorithm is a rather easy process to evaluate the dynamics of a CNC system. This is one of the most commonly used ways and anyone with little technical knowledge can do it. This is precisely what I've done and the results are as expected.

6.REFERENCES

[1] Sencer, B., & Altintas, Y. (2011). Identification of 5 axis Machine Tools Feed Drive Systems for Contouring Simulation. *Identification of 5 Axis Machine Tools Feed Drive Systems for Contouring Simulation*, 377–386.

All the parameter values and linear equations are taken from the above reference paper.