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Variable Speed Control Using Fuzzy-PID Controller for Two-phase Hybrid Stepping Motor in Robotic Grinding

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Abstract

In a robotic grinding process, a light-weight grinder is held by an intelligible robot arm. Material removal is carried out by the rotating grinding tool while the end effector of robot guarantees that the tool follows a programmed path in order to work on complex curved surfaces. Grinding tool is driven by Two-Phase Hybrid Stepping motor derive. This work aims to develop a controller based on fuzzy logic to improve the speed control performance of Two-Phase Hybrid Stepping motor derive in order to achieve a controller that provides grinding with higher quality. The analysis and design of PID-Fuzzy controller to improve the response of the motor speed were studied. This paper simulates six motor speed input conditions. The simullink package of the MATLAB. Comparison between the conventional PID controller and Fuzzy-PID output was done on the basis of the simulation result obtained by MATLAB. The simulation results demonstrate that the designed Fuzzy-PID controller realize a good dynamic behavior of the Two-Phase Hybrid Stepping motor, a perfect speed tracking with less rise and settling time, minimum overshoot, minimum steady state error and give better performance compared to conventional PID controller.

Keywords: f*orce control, speed control, PID controller, fuzzy logic controller, PID-Fuzzy controller, two-phase hybrid stepping motor, grinding robot.*

1. Introduction

Robotic grinding, in early industrial applications, was resolved using a grinding machine attached to the end effector of robot through a damper and spring arrangement. In the process of grinding and finishing, grinding force needs to be actively controlled both in direction and in value all the time along with feed movement controlling, thus the process requires to be controlled by the policy of compliant controlling. When the force controlled robot is applied to grinding operation, the position control style is selected to control the grinding tool path in the feed direction exactly. In the press direction, which is perpendicular to the feed direction, the compliance control style or force control style is selected to get the appropriate contact force. It is essential to maintain a suitable amount of contact force in grinding operation, and as well to take into account the workpiece profile after grinding. Either compliance control or force control can be chosen. In the force control style, the grinding tool follows the surface of workpiece by maintaining the contact force constant in order to provide equally grinding on the whole surface. So it is possible to follow an unknown curved surface. The grinding process can be finished easily without taking into account the position errors like for example in setting the workpiece that is the problem when using a position controlled robot. This style therefore is most successfully for grinding a surface usually made or in small deburring of machined parts. In the compliance control style, the requested profile of the workpiece surface after grinding process performs as the reference position; also the contact force is accomplished by contraction or expansion of virtual spring. So it is possible to produce a target profile after grinding. Then, it must be compensate the large error of workpiece position that can't be corrected by virtual

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spring. This style is appropriate for grinding to get a target profile as an example of large deburring of casting [1].

The hybrid movement–force control policy is the best way for a compliant control system to deal with the coupling of the force control subsystem and the movement control subsystem. In this paper the grinding tool is driven by Two-Phase Hybrid Stepping motor derive. Stepper motors were chiefly used for simple point-to-point positioning tasks in which they were open-loop controlled. In the open-loop control system, without feedback, there is no way to know if the speed response is oscillatory or if the stepping motor has missed a pulse. It shows a poor dynamic performance and suffers from lack of ability to be modified to load variations and system variations. In order to increase the accuracy positioning of the stepping motor, closed-loop control principle was introduced in the 1970's, as long as making it less sensitive to load disturbances. The closed-loop control is characterized by starting the motor with one pulse, and the following drive pulses are generated as a function of the motor shaft speed and/or position by the use of a feedback encoder [2].

Nowadays, due to advances manufactured in both data processing and power electronics, stepping motors are further frequently closed-loop controlled, in special, for robotics manipulators and machine tools in which they have to present high-precision operations in spite of the mechanical formation changes. The conventional proportional–integral–derivative (PID) controllers stay to be the most prevalently used in the industrial processes in spite of the many complicated control techniques and theories that have been invented in the last few decades [5] The PID controller attempts to minimize the error by modifying the process control input [10]. The famous method, Ziegler–Nichols method, supplies a systematic tuning method for the PID parameters which has good load disturbance reduction but, with a long settling time and large overshoot it shows disappointing performance. In addition, using of proportional-integral-derivative (PID) control as a classic closed-loop algorithm is not perfect because these algorithms are not insensitive quite when confronted by mechanical configuration changes [3].

The serious problems in applying a proportional-integral-derivative (PID) in a speed controller are the effects of non-linearity in the Two-Phase Hybrid Stepping motor. The nonlinear characteristics of the motor such as fiction and saturation could degrade the performance of conventional controllers [4]. Mostly, it is difficult to find an accurate nonlinear model of an actual Two-Phase Hybrid Stepping motor and parameter achieved from systems identification possibly only approximated values. In recent years, fuzzy control field has been making rapid progress [5].

In this paper, an optimal Fuzzy-PID controller is proposed to control the variable speed of a two phase hybrid stepping motor drive. The application of fuzzy theory in the closed-loop control system entails in combine engineering knowledge into the automatic control system by using the experience and intuition of the designer.

The policy was proposed by Zadeh in 1965 to describe complicated systems, which are hard to analyze using traditional mathematics. Fuzzy logic theory has found wide commonness since the 1970's in various applications such as management, medicine, economics, or control process. In fact, Mamdani et al. were the first to present the application of fuzzy set theory to control a small laboratory steam engine. This study’s successful led many researchers to try to control industrial processes such as nuclear or chemical reactors and automatic trains using fuzzy algorithms. The results of these experiments showed that fuzzy controllers perform better. Furthermore, this technique offers the advantage of demanding only a simple mathematical model to formulate the algorithm, which can absolutely be implemented by a digital computer. These features are esteemed for nonlinear processes for that there is no reliable model and complex systems where the model is not practical because of the large number of equations involved [6]. In the past decade, common researches attempt on fuzzy logic control have been dedicated to model-based fuzzy control systems that assure stability and the closed-loop fuzzy control systems performance. It has a rare feature of simplicity and its flexibility to deal in problems with exactness and accuracy with its simulation results. It can be carried out in software or hardware or by joining of both of them.

F Betin D Pinchon, G Andre, 2000 [3], suggested the application of fuzzy logic theory to control speed of a permanent magnet stepper motor drive with feedback. Using simulation software of stepping motor dynamics, the most efficient topology of the fuzzy controller has been determined. An advanced test bed was used to confirm experimentally the insensitivity to external disturbances, the tracking capacities, and for parameter changes. The study has also proved that the fuzzy control is absolutely implemented using a low-cost single-chip microcontroller. Also, this method does not require a fixed sampling time. Therefore the proposed design approve that fuzzy control is related to the control of fast nonlinear processes where quantitative techniques are not always suitable.

KS Cheol, CY Sung, PJ Hyung, KaSChul, BGHan, 2005 [7], designed a stepper motor drive using a fuzzy logic control based on PID-controller to enhance robust characteristic in which the deviation of external load affect parameter. They could not acquire rabidly response, but robustness in disturbance.

The aim of this paper is the development of fuzzy controller to simulate the automatic of feedback control of the tow phase hybrid stepping motor operation with various speed. PID and Fuzzy – PID controllers are advanced and their responses are to be compared.

2. Tow-phase Hybrid Stepping Motor

2.1 Stepper Motors

Stepper motors are a kind of electromagnetic mechanical devices which can transform discrete electric impulses (typically square wave pulses) into linear or angular displacement. Each pulse moves the shaft through a fixed angle. The rotation speed of stepper motors is directly proportional to the frequency of the input pulses, and their output angular displacement is directly proportional to the amount of the input pulses [8].

They are usually used in control and measurement applications because of their benefit of easy open-loop control and no accumulating error.[9] Stepping motors are the perfect choice for the applications with small power (less than 100 watt) while position control must be fast and sharp, such as in robotics, machine tools, servos, aerospace applications, printers, and scanners [10]. Stepper motors are fast and executable in many performance hardware. The utilize of stepper motors has increased few years later as a result of:

a. Its better reliability due to the mechanical brushes elimination,
b. Higher torque-to-inertia ratio due to a lighter rotor,
c. Its better heat dissipation due to that the windings are situated on the stator not on the rotor, and Inexpensive.

Originally, stepper motors were designed to be employed in open-loop. Their intrinsic stepping capability allows for perfect positioning without feedback, then closed-loop control of stepper motors has been employed to achieve more rapid response times and higher resolution capabilities. The stepper motor can also be operated at higher speeds, by taking into consideration nonlinear effects [11]. Stepper motors impressively have multiple "toothed" electromagnets arranged around a central gear-shaped piece of iron. General stepping motor with its main parts is showing in Figure 1 [12].

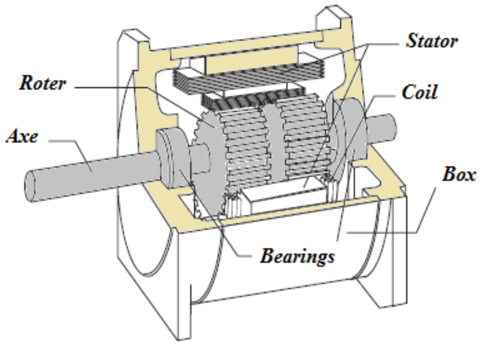


Figure 1. General Stepping Motor with its Main Parts

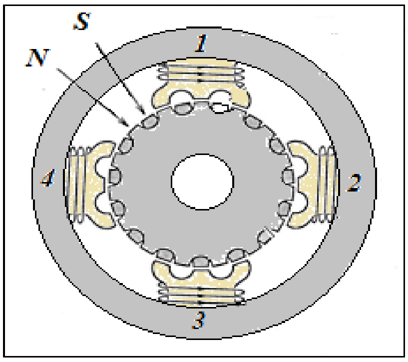


Figure 2. Cross-Section of a Stepper Motor.

The electromagnets are invigorated by a microcontroller or an external driver circuit. To make the motor shaft turn, previously, the top electromagnet (1) is turned on by given power, it will magnetically attracts the nearest teeth of the gear-shaped iron rotor. The gear's teeth will be slightly offset from the next electromagnet right electromagnet (2). When the right electromagnet (2) is energized and the top electromagnet (1) is turned off, it will pull the teeth into alignment with it. This means that the gear rotates slightly to align with the next one when the next electromagnet is turned on and the first is turned off. The process is repeated from there. Each of those rotations is called a "step", making a full rotation with an integer number of steps, for example, it will take 100 steps to make a full rotation if there are 25 teeth. In that way, the motor can be turned by an exact angle.

Stepper motors have various merits such as small inertia, great output torque, and high frequency response. These characteristics donate to the wide usage in the industry nowadays, especially in control applications and measurement [8]. They have also some demerits such as step response with relatively long settling time and overshoot. In addition, when steps of high frequency are given, loss of synchronism appears. Therefore it is necessary to develop control systems to improve the performance of stepper motors [13].

2.2. Hybrid Stepping Motor

Among several types of the stepping motors, the motor that contain the permanent magnet rotor and many teeth both on the rotor and stator poles is called the Hybrid Stepping Motor. They are the most commonly used in the industry, as this keeps the power electronic circuits relatively simple and because of their higher efficiencies over the variable-reluctance-permanent magnet type stepping motors.

It was originally designed for low-speed applications as an AC two-phase synchronous motor. Theoretically, the motor can be regarded as a multipole synchronous motor. Recent require for high-torque low-speed motors makes the hybrid stepping motor more interesting compared to the conventional ac motors such as synchronous motors and induction motors[14]. Hybrid (HB) The hybrid stepper motors provides better performance with respect to step resolution, speed and torque. They combine the best features of both variable reluctance and permanent magnet stepping motors. The rotor is multi-toothed like the variable reluctance motor and contains, around its shaft, an axially magnetized concentric magnet. The teeth on the rotor supply an even better path that helps guide the magnetic flux to favored locations in the airgap. This more increases the detent, grasping and dynamic torque characteristics of the motor when compared with both the permanent magnet and variable reluctance types.

The two-phase hybrid stepping motor is clarified in cross-section in Figure 3 [15] and consists essentially of a rotor and stator, typically both are assembled from stacked laminations of electrical grade steel.

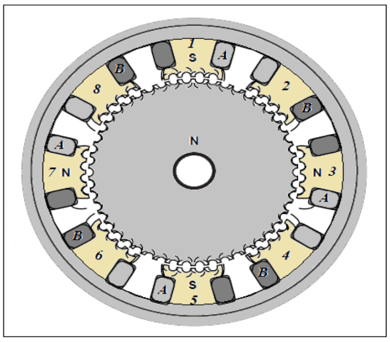


Figure 3. Cross-section of Two-Phase Hybrid Stepping Motor.

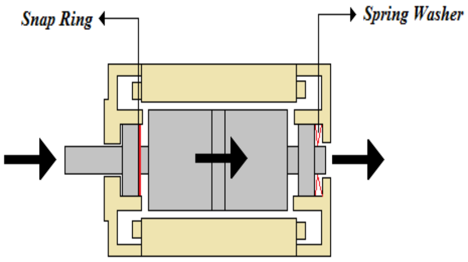


Figure 4. Longitudinal Section of Two-Phase Hybrid Stepping Motor

The stator has eight poles; each phase has four of them, which broaden at the tips to a group of teeth. Every stator pole has a twisting in the form of a short pitched phase coil. Usually, these are connected in series to form two electrically independent motor phases, A and B shown in Figure 3. The rotor has a large number of teeth (typically 50) and embodies a permanent magnet in the center of it. The permanent magnet products static flux along the axis of the machine. The rotor tooth pitch is the same as that of the stator [16]. In a two phase stepper motor, there are two basic winding arrangements for the electromagnetic coils: bipolar and unipolar. Bipolar stepper motors have a single winding per phase and unipolar stepper motor has one winding with center tap per phase. Standard hybrid stepper motors are assembled with a spring washer that applies pressure on the ball bearings in order to reduce bearing noise, keep the rotor in position, and increase bearing life. Also, to prevent unwanted shaft movement, motors are supplied with a snap ring behind the front bearing which locks the bearing in position even under very heavy axial loads, see Figure 4.

3. Mechanical Parameters of Two-Phase Hybrid Stepping Motor

A completely model of a two-phase hybrid stepping motor consists of the shaft mechanical dynamics together with the electrical dynamics of the stator coils. The electric response is faster more than the mechanical response, enabling us to consider the mechanical dynamics only [17]. So that, the performance of the two-phase hybrid stepping motor system (driver and motor) is dependent on the mechanical parameters of the load which is what the motor drives. It is typically inertial, frictional or a combination of them.

Inertia is the resistance to changes in speed, when inertial load increase, the speed stability and the amount of time it takes to reach a desired speed will increase while the maximum self start pulse rate will decrease. The converse is true if the inertia is decreased. This mean that a high inertial load demands a high inertial starting torque and, for braking, the same would apply.

Friction is the resistance to motion due to the rough of surfaces which rub together. Friction is constant with velocity, when a frictional load Increase, the top speed and the acceleration will decrease, while the positional error will increase. The converse is again true if the frictional load is decreased. It means that a minimum torque level is demanded during the step in over to defeat the friction (at least equal to the friction). The rotor oscillations of the two-phase hybrid stepping motor will vary with the amount of inertia load and friction. Because of this undesirable relationship, the rotor oscillations can be decreased by mechanical damping ways as by switch from full step drive to half step drive or by other electrical damping methods. Also it can be reduced by Passive compliance which is an additional tool or a device attached to the grinding tool that holding by the robot end-effector to provide a flexibility for it. It is useful for the self-correction of positioning errors in assembly, normally reduce the high forces or moments produced in wedging or jamming, passive compliance protect the assembled surfaces from damage, such as a galling or scraping; it is useful also for adaptation to the impermanent state control and force control.

This paper present a helix spring and compliant wrist to be the passive compliance additional tools as shown in Figure 5.

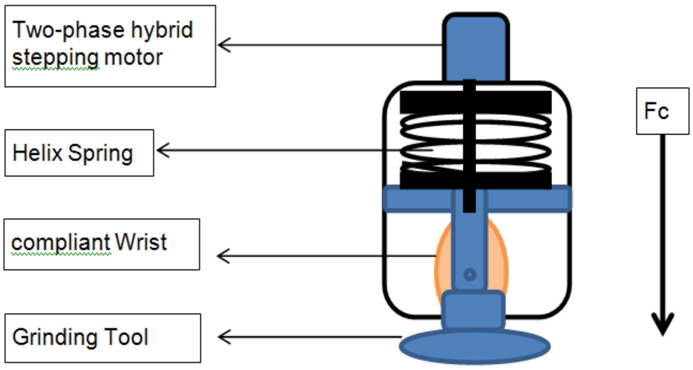


Figure 5. Model of the Grinding Force Servo System

4. Torque & Speed Characteristics of Two-Phase Hybrid Stepping motor

Each pole of the two-phase hybrid stepping motor is covered with uniformly spaced teeth that are arranged in an improper with each other by a half-tooth pitch. The interaction of the magnetic field produced by the stator and the magnetic field of the permanent magnet and create torque.

A typical "speed - torque curve" of a two-phase hybrid stepping motor is shown in Figure 6 [18]. We can see from it that the step rate influences the torque output capability of the motor. The decreasing torque output when the speed increases is caused by the fact that at high speeds the inductance of the motor is the dominant circuit element.

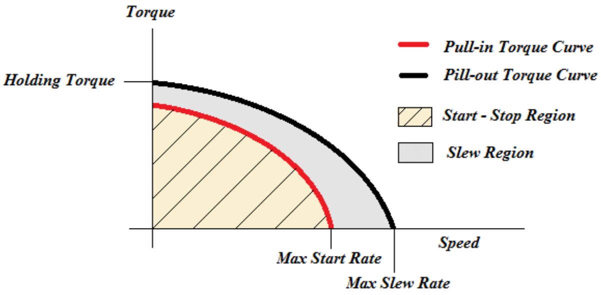


Figure 6. Torque vs Speed Characteristics of a Stepper Motor.

Due to the fact that motor performance varies greatly with the drive at variable speed, holding torque is used to rate the two-phase hybrid stepping motors. Holding torque is the maximum torque that can be applied to the motor shaft and not cause the shaft to rotate. It is energized with rated DC current and measured with the motor at standstill.

The pull-in torque curve limits an area referred to the start stop region. With a load applied and without loss of synchronism, this is the maximum frequency at which the motor can start/stop instantly. The maximum start rate is the maximum starting step frequency with no load applied. The pull-out torque curve defines the maximum frequency at which the motor can set in motion without losing synchronism. It limits an area referred to as the slew region. The motor must accelerated or decelerated into this area since it is outside the pull-in torque area. The maximum operating frequency of the two-phase hybrid stepping motor with no load applied is called the maximum slew rate. A block diagram of a hybrid stepping motor and drive is shown in Figure 7 and consists of a hybrid stepping motor, power converter and controller.

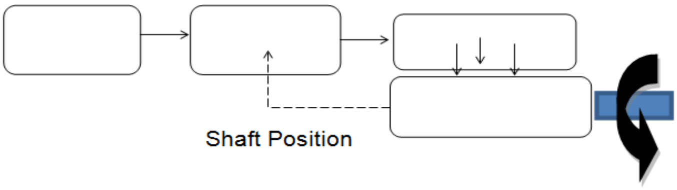


Figure 7. Hybrid Stepping Motor Drive Block Diagram

5. The Model of the Two-Phase Hybrid Stepping Motor

From Figure 8 the transfer function G(s) of the open-loop system of the two-phase Hybrid Stepping Motor is as follows [19]:

$$G(s) = A(s) / B1(s) + B2(s) \tag{5}$$

Where:

A(s) = Kpv +KIv / s +KDv s) (KPi s+ KIi)ke NKH (6)

B1(s) = JLs^4 +(JR+βL+JKPi KH) s^3 (7)

B2(s) = βKIi KH s+(JKIi KH + βR+βKPi KH)s^2 (8)

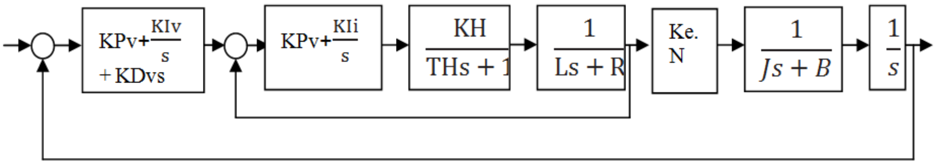


Figure 8. The Model of the Two-Phase Hybrid Stepping Motor

The subdivided driving is assumed for the Hybrid Stepping Motor in order to reach to the actual system performance parameter and to decrease the intricacy of the system transfer function. In simulation, the parameters of the two-phase Hybrid Stepping Motor selected are as follows:

Inductance L= 4.5mH, Resistance R = 1.3Ω, Inertia Constant J = 270 kg·m,
Coefficient of Viscous Friction B = 0 N · m · s/rad, β = 1,
Kpv = 550, KIv = 0, KDv = 115,
ke = 0.25 N · m/A, N = 180, KH = 10, KIi = 550, KPi = 6.
Transfer function will be :
G(s) = 270000 s^2+28350000 s+135000000 / s^4+19799 s^3+650000 s^2+7500s

6. Step Response of a General Control System

The step response of a general control system is a common analysis tool used to determine the performance of the control system. It is the output of the system produced by a unit step input. The step response can be delineated by four quantities: Overshoot, Rise Time, Settling Time, and Steady State Error as shown in fig.9. These terms are defined as:

a. The overshoot represents a distortion of the signal. It is the maximum swing above final value.
b. Rise time is the time demanded for the output to change from an indicated low value to an indicated high value, approximately 90% of the final value. It will increase with increased damping.
c. The settling time is the amount of time to get within some envelope near the final value (approximately 10% of final value). It directly affects robot cycle time, therefore, each try should be made to minimize this value.
d. Steady State Error is the minimum error after settling.

In this paper, the performance measure to be minimized the PID controller following objectives as the rise time, the maximum overshoot and Minimize the settling time. We assume and simulate six motor speed input conditions. Figure 10, 11 show the steps of motor speeds condition. At the step time =1, the first initial motor speed value is equal to zero, the final value is 2, which is reduced to -1 in in the step time = 2, and then is returned to 1, the fourth motor speed final value of -1 in the step time from = 4 which is increased to 1 in in step time = 6, and still at the same speed =1 at step time = 8, so as to observe the steps of the control system under variable motor speed conditions =10 .

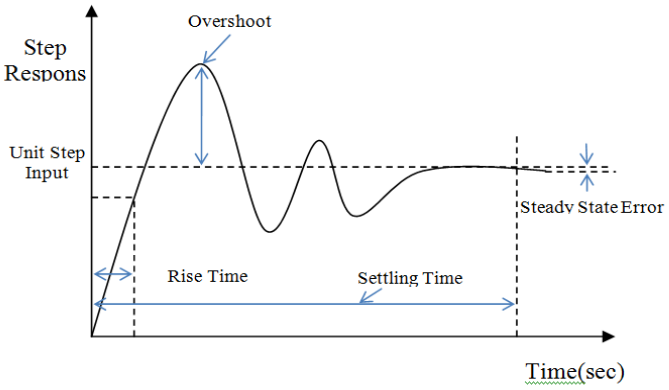


Figure 9. The Step Response of a General Control System

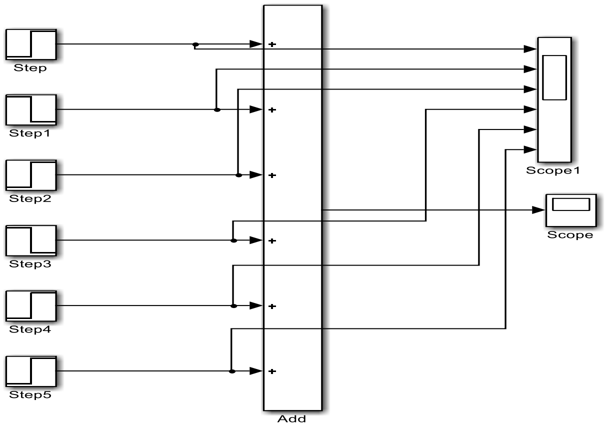


Figure 10. The Motor Speed Steps Input

6. Conventional PID Strategy for Grinding Force Servo Unit

Proportional-Integral-Derivative (PID) controller is the most greatly used in industrial applications. It is easy to tune and it has good disturbance attenuation properties. The disadvantage of PID controller is that it is linear and cannot successfully control a plant that has robust nonlinearities.

The PID controller uses incremental PID algorithm, the formula as follows.

$$\Delta u(k) = K_p * N_e + K_i * N_{sp} + K_d * (N_e - N_{elast}) \qquad (9)$$

Where:
Nsp = Nref-n, is the current motor speed error,
Nref is a given speed, n is the actual speed.
Ne=Nsp-Nsp0 is the current speed error variation.
Nsp0 is the speed error on the previous moment.
Nelast is the speed error variation of the previous moment [20]

The most conventional PID controller or linear PID controller is described as follows:

$$u(t) = K_p e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt}$$

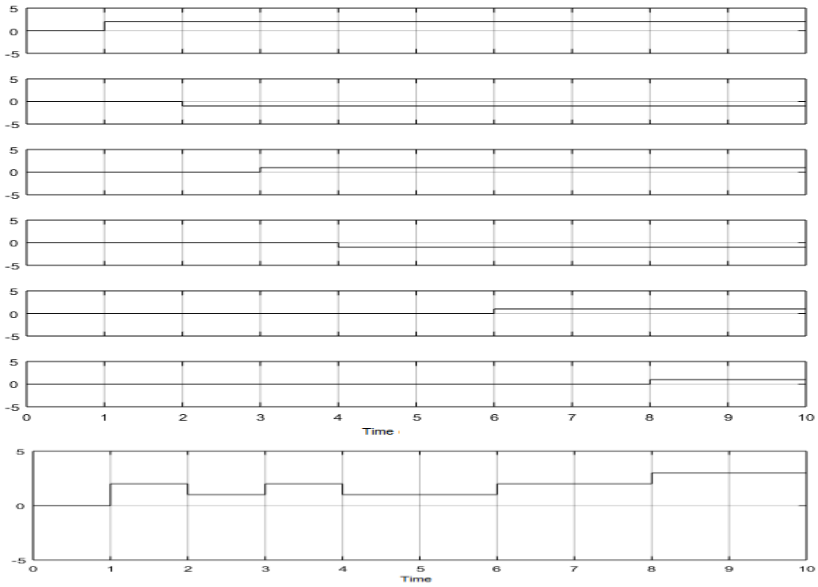


Figure 11. Changes within Step Input Variable Motor Speed

Where KP is the proportional constant gain, KI is the integral constant gain and KD is the derivative constant gain according to manual expertise. The signal e(t) is the error signal between the reference and the process output c(t) it is explained as:

$$e(t) = r(t) - c(t)$$

Table 1. Shows the Effect of Kp, Ki and Kd to the Controlled System

parameter	Rise time	Overshoot	Turning time	Error
Kp	decrease	Increase	Small change	decrease
Ti	decrease	Increase	increase	eliminte
Td	Small change	Decrease	decrease	Small change

The Simulink figure of PID controller is shown in Figure 12

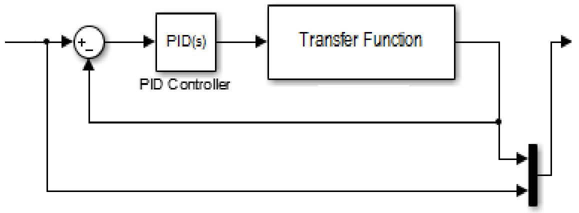


Figure 12. Simulink Figure of PID controller

The PID controller internal structure is explained in Figure 13, the input parameters for the PID controller are Kp, Ki, Kd, e and ec, the output for the controller is u.

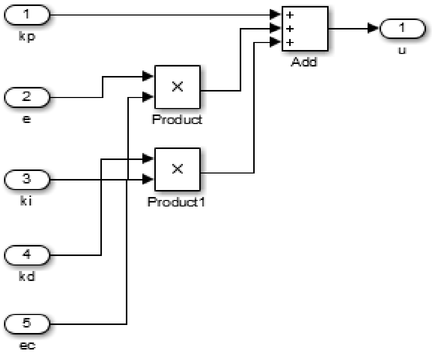


Figure 13. The Structure for PID Controller

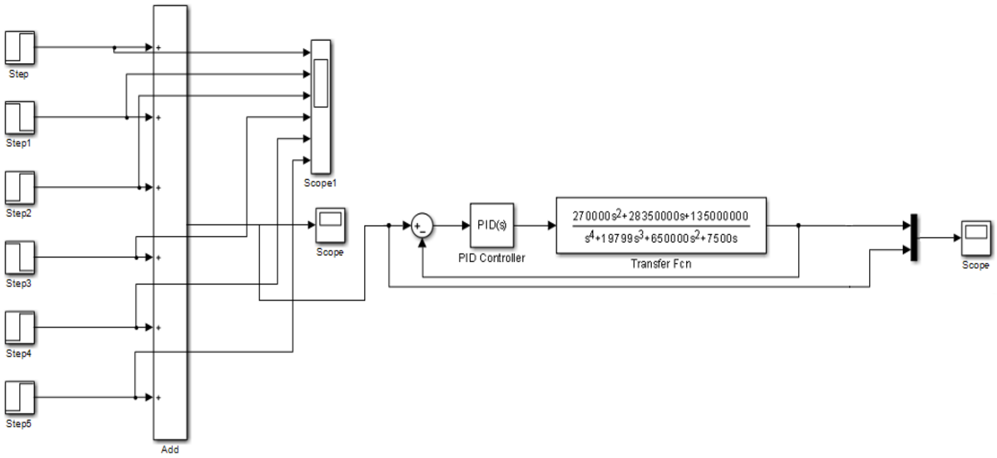


Figure 14. Simulink Figure of Variable Speed PID Controller

7. Fuzzy Controller Strategy for Grinding Force Servo Unit

Fuzzy logic is widely used in processes where system dynamics is either very complex or show an extremely nonlinear character. The fuzzy controller operation can be described as shown in Figure 15:

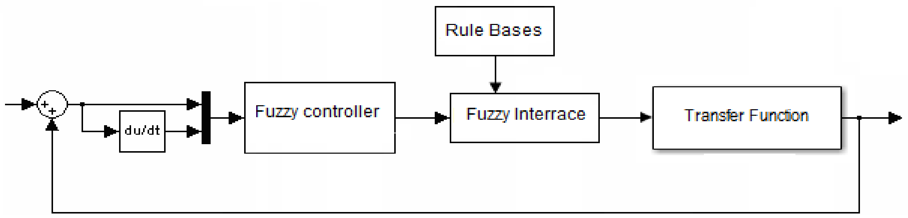
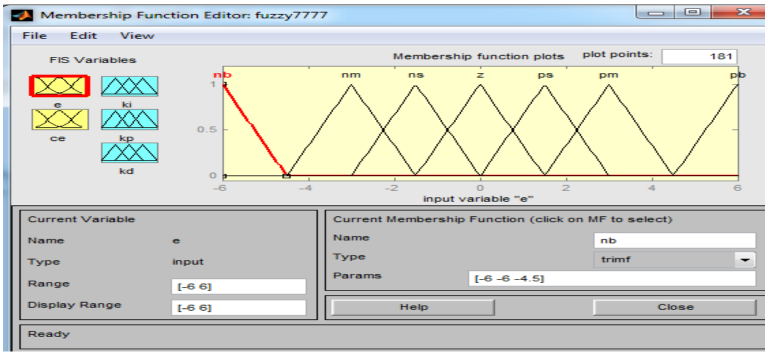


Figure 15. The Structure for Fuzzy Controller

In this paper, Fuzzy subsets of all inputs and outputs are total explained as {NB, NM, NS, Z, PS, PM, PB}. Elements of every subset refer to: negative large Nb, negative middle Nm, negative small Ns, zero Z, positive small Ps, positive middle Pm and positive large Pb.

We set the ranges {−6,6} for both e and ec, {−1,1} for both Kd and Ki and {−3,4} for Kp as shown in Figure 16-20.



Current Variable

Name e

Type input

Range [-6 6]

Display Range [-6 6]

Current Membership Function (click on MF to select)

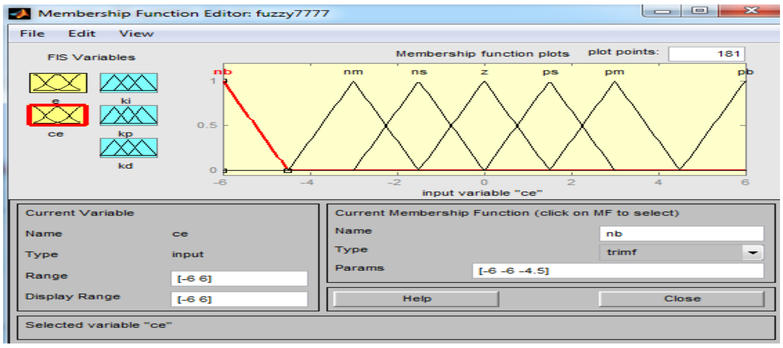
Name nb

Type trimf

Params [-6 -6 -4.5]

Ready

Figure 16. Membership Error Function (e)



Current Variable

Name ce

Type input

Range [-6 6]

Display Range [-6 6]

Current Membership Function (click on MF to select)

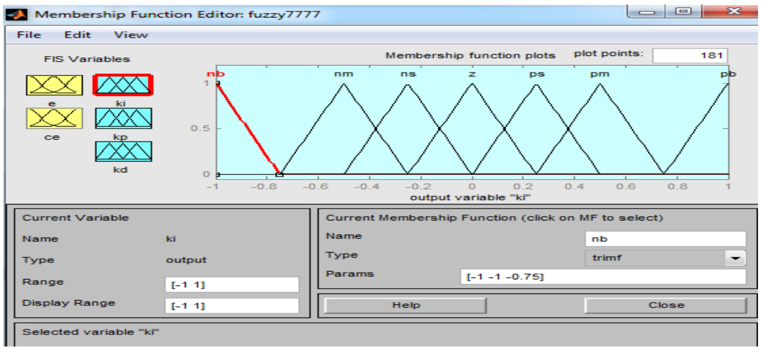
Name nb

Type trimf

Params [-6 -6 -4.5]

Selected variable "ce"

Figure 17. Membership Change Error Function (ec) of Fuzzy



Current Variable

Name ki

Type output

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

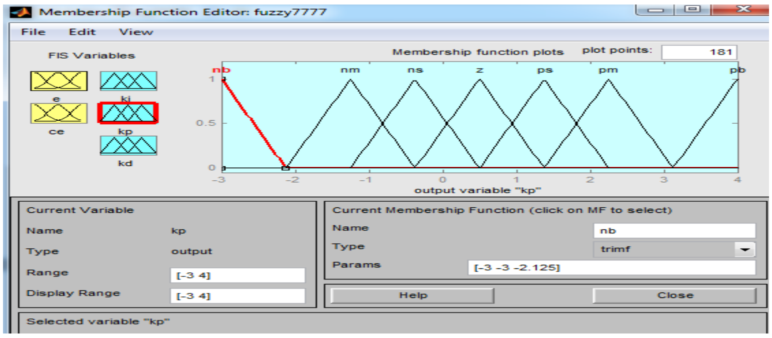
Name nb

Type trimf

Params [-1 -1 -0.75]

Selected variable "ki"

Figure 18. Membership Ki Function of Fuzzy Controller



Current Variable

Name kp

Type output

Range [-3 4]

Display Range [-3 4]

Current Membership Function (click on MF to select)

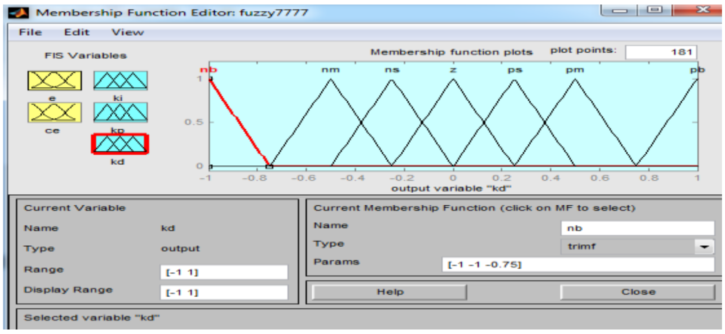
Name nb

Type trimf

Params [-3 -3 -2.125]

Selected variable "kp"

Figure 19. Membership Kp Function



plot points: 181

Name kd

Type output

Range [-1 1]

Display Range [-1 1]

Name nb

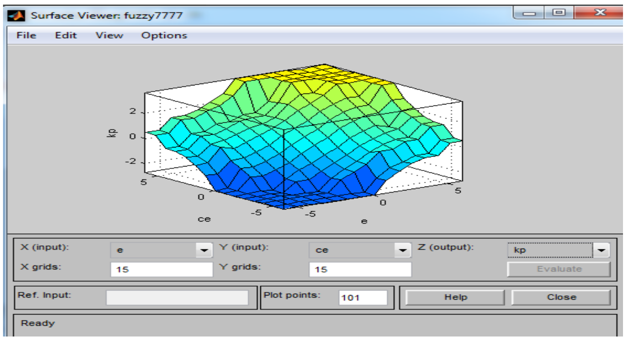
Type trimf

Params [-1 -1 -0.75]

Selected variable "kd"

Figure 20. Membership of Kd Function

The surface view of Kp, Ki, and kd will be as shown in Figure 21- 23.



X (input): e

Y (input): ce

Z (output): kp

X grids: 15

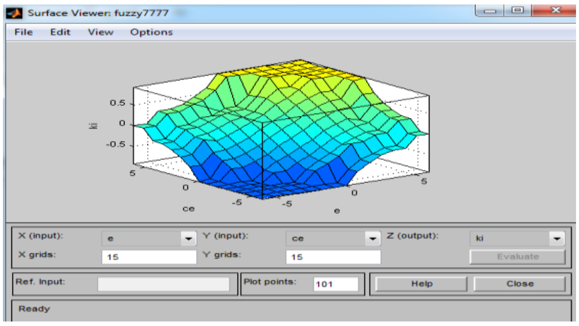
Y grids: 15

Ref. Input:

Plot points: 101

Ready

Figure 21. Surface View of Kp of Fuzzy Controller



X (input): e

Y (input): ce

Z (output): ki

X grids: 15

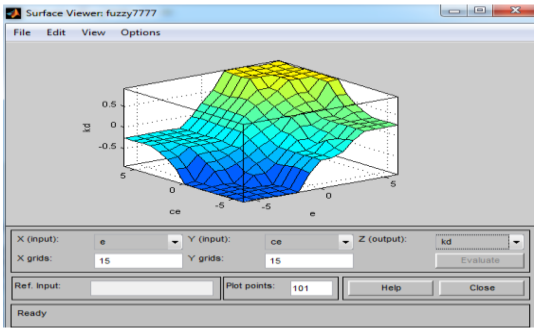
Y grids: 15

Ref. Input:

Plot points: 101

Ready

Figure 22. Surface View of Ki of Fuzzy Controller



X (input): e

Y (input): ce

Z (output): kd

X grids: 15

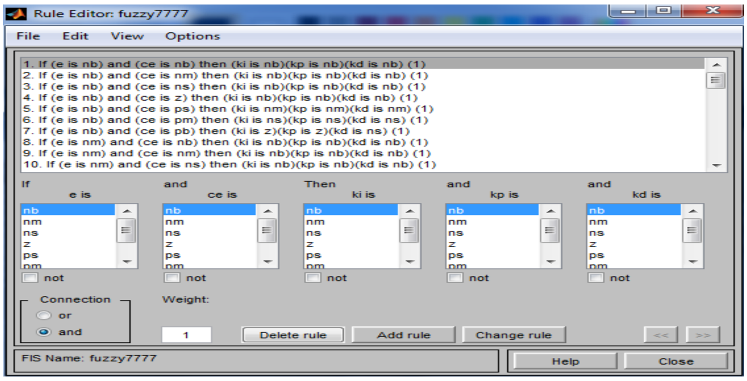
Y grids: 15

Ref. Input:

Plot points: 101

Ready

Figure 23. Surface View of Kd of Fuzzy Controller

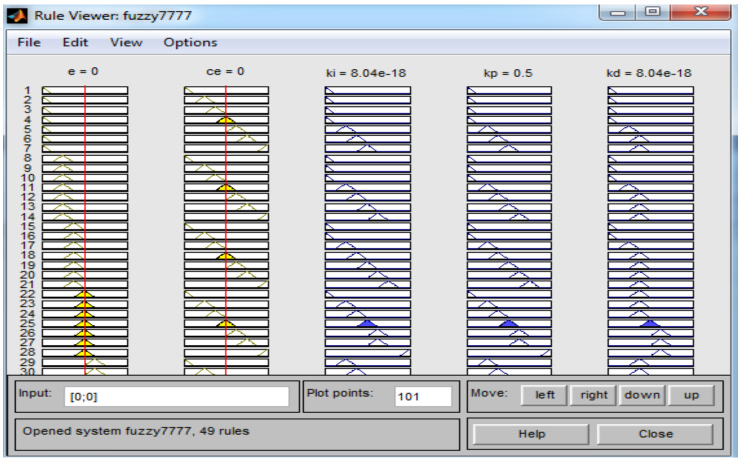


1. If (e is nb) and (ce is nb) then (ki is nb)(kp is nb)(kd is nb) (1)
2. If (e is nb) and (ce is nm) then (ki is nb)(kp is nb)(kd is nb) (1)
3. If (e is nb) and (ce is ns) then (ki is nb)(kp is nb)(kd is nb) (1)
4. If (e is nb) and (ce is z) then (ki is nb)(kp is nb)(kd is nb) (1)
5. If (e is nb) and (ce is ps) then (ki is nm)(kp is nm)(kd is nm) (1)
6. If (e is nb) and (ce is pm) then (ki is ns)(kp is ns)(kd is ns) (1)
7. If (e is nb) and (ce is pb) then (ki is z)(kp is z)(kd is ns) (1)
8. If (e is nm) and (ce is nb) then (ki is nb)(kp is nb)(kd is nb) (1)
9. If (e is nm) and (ce is nm) then (ki is nb)(kp is nb)(kd is nb) (1)
10. If (e is nm) and (ce is ns) then (ki is nb)(kp is nb)(kd is nb) (1)

Weight: 1

FIS Name: fuzzy7777

Figure 24. Rule Bases for Fuzzy Control System



e = 0

ce = 0

ki = 8.04e-18

kp = 0.5

kd = 8.04e-18

Input: [0;0]

Plot points: 101

Opened system fuzzy7777, 49 rules

Figure 25. Rule Bases View for Fuzzy Control System

8. Fuzzy-PID Strategy for Grinding Force Servo Unit

In this paper, Fuzzy-PID strategy which combines the Fuzzy optimizing strategy with the conventional PID algorithm. In this strategy, the optimal values for the three characteristic parameters of a PID controller are obtained by Fuzzy self-optimizing.

The Fuzzy-PID controller principle is shown in Figure 26, in which e refers to the error of the output from its desired value and ec = de/ dt.

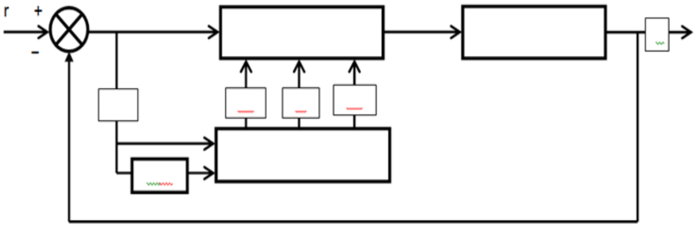


Figure 26. The structure of Fuzzy-PID Controller

By Fuzzy optimizing, the values of the three characteristic parameters would be: Kp=200, Ki=14.75, Kd=3.6875.

In Figure 27, there are two inputs and three outputs for the Fuzzy Logic Controller, the inputs are (e) and (ec = d/dt), and the outputs are Kp, Ki and Kd.

With the MATLAB SIMULINK, a famous simulation software, and for a conventional PID controlling system, step response is also shown in Figure 4 with Kp=200, Ki=14.75, Kd=3.6875. Step response of the Fuzzy-PID controlling system is completely different from that of the conventional PID controlling system.

Remarkably, the Fuzzy-PID controller has improved the force servo system by deducing the optimized Kp, Ki and Kd

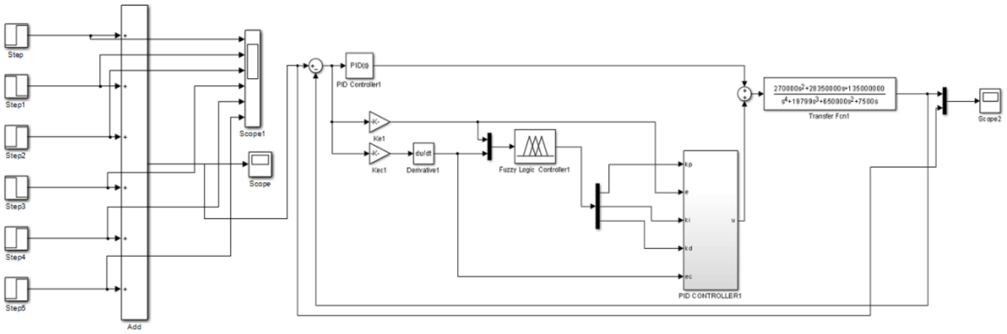


Figure 27. The Fuzzy-PID Simulation Model in MATLAB

10. Results and Discussion

10.1. Two-phase Hybrid Stepping Motor with PID Controller: Modeling

Figure 28 shows the Simulink figure of PID controller. When Kp=2, Ti = 0.5, Td= 1, the simulation was performed in figure:

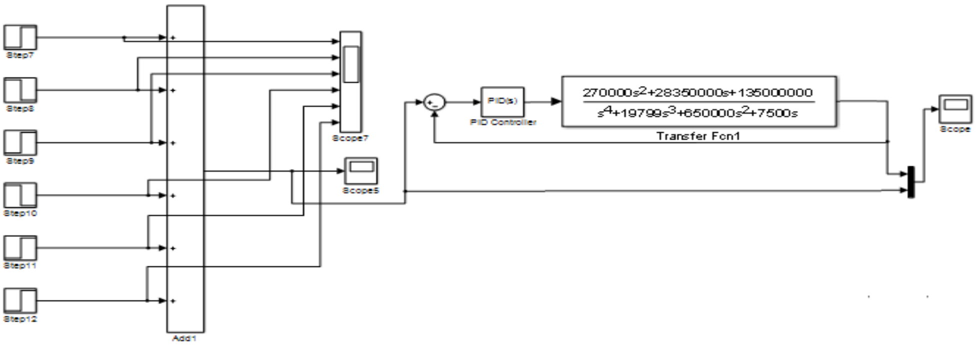


Figure 28. Simulink Figure of PID Controller

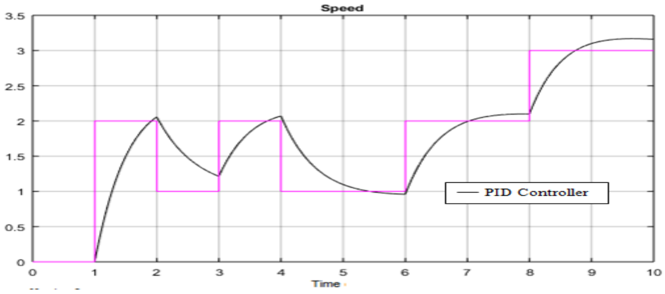


Figure 29. Step Response of the System Under PID Controller

10.2. Two-phase Hybrid Stepping Motor with Fuzzy Controller: Modeling

We note that there is an undershoot value.

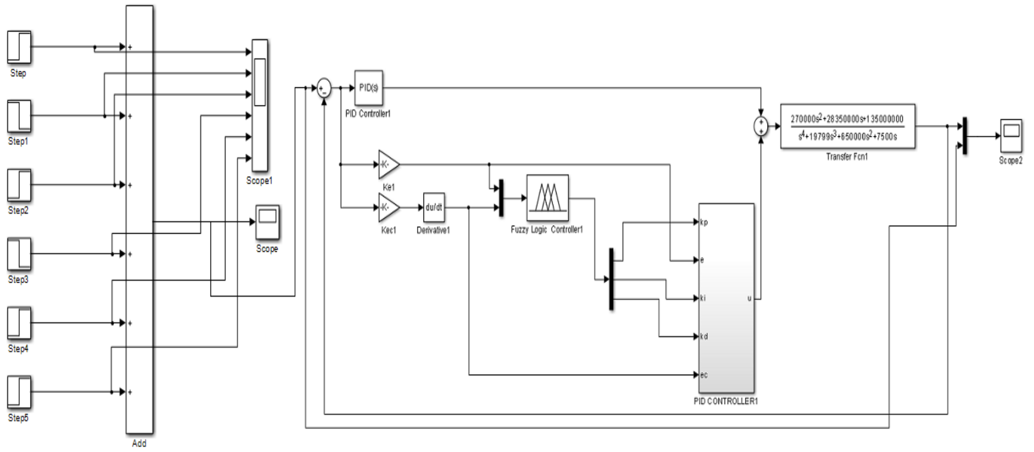


Figure 30. Simulink Figure of Fuzzy Controller

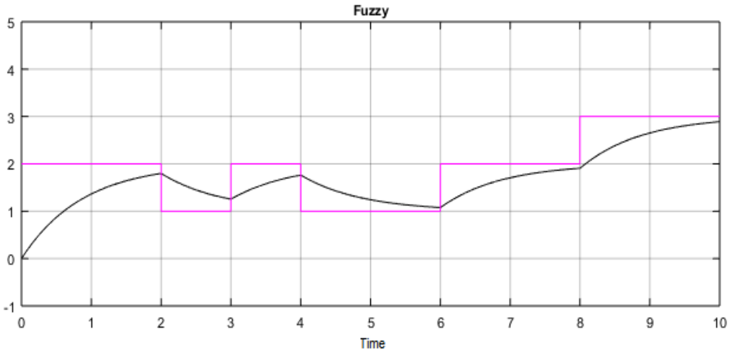


Figure 31. Step Response of the System under Fuzzy Controller

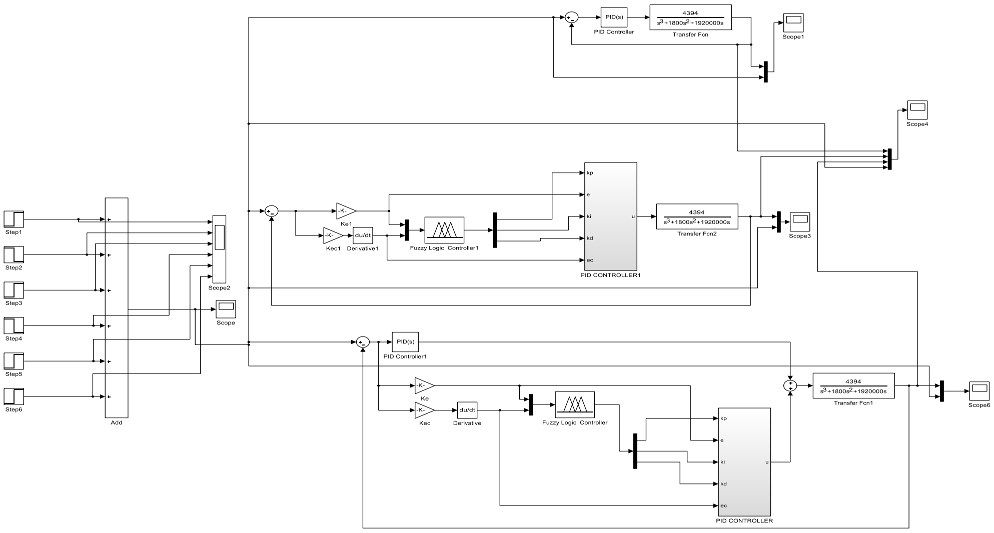


Figure 32. The Hole Variable Speed Controller System of the Two-Phase Hybrid Stepping Motor

10.3. Two-Phase Hybrid Stepping Motor with Fuzzy-PID Controller: Modeling

The hole system of the controller is shown in Figure 32, and Step response of the Fuzzy-PID controlling system is shown in Figure 33.

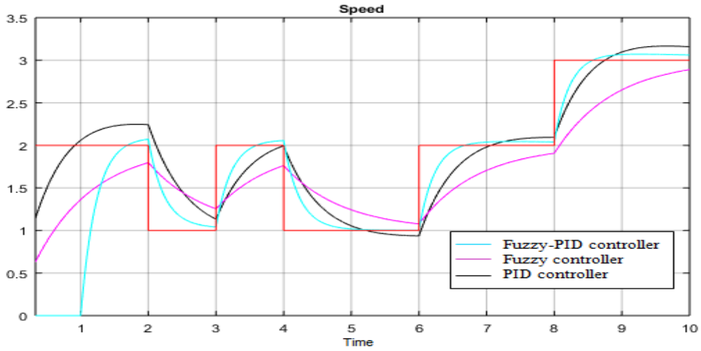


Figure 33. Step response of the System Under PID, Fuzzy & Fuzzy-PID Controllers

Step response of the Fuzzy-PID controlling system is completely different from that of the conventional PID and Fuzzy controlling systems. For each step, as shown in Figure 15, we note that when we used PID controller: the rise time value, the overshoot value, and the steady state error value are higher than if we use Fuzzy controller. Also we note an under shoot value with using Fuzzy controller. While when we use Fuzzy-PID controller we note that the Rise Time value, the Overshoot value and Steady State Error are reduced for each step with no under shoot value.

Remarkably, the Fuzzy-PID controller has improved the variable speed control system by inferring the optimized Kp, Ki, Kd.

11. Conclusion

In this work, the close loop control for the two-phase hybrid stepping motor derive has studied and presented. Fuzzy logic based controller (fuzzy-PID) has also studied and presented. Results for one parameter was monitored, namely, the speed of the motor (step/sec). The results were obtained using Simulink representation of the Two-Phase Hybrid Stepping Motor transfer function have been done using the software package MATLAB/SIMULINK.

Analysis and comparison of the results presented for the following conclusion:

a. The time response of the motor speed can be effectively suppressed by the two model; excitation sequence and load torque.
b. By adding fuzzy control tools fuzzy PID-controller to the motor speed control make its response with low effect on the rise time, and low peak over shoot.
c. In this work we proved that fuzzy control is related to the control of fast nonlinear processes such as Two-Phase Hybrid Stepping Motor drives.

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