

# Modeling and Analysis of Milling Machine Control Process without/with Using Fuzzy Interface Mamdani Style Based On Matlab/Simulink

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## Abstract

*Because of time-varying, nonlinearity and complexity of machining process, the traditional PID control has been unable to meet the requirements. However fuzzy control can be a good solution for this kind of control system. This article aims to establish a milling control process model according to the logic of cutting process mathematical terms with a servo system and give it appropriate processing parameters selected from reading references. The final model will be represented by using Simulink blocks. To insure the model is correct and comparable, the Matlab code will test the step response under various parameters, then fuzzy interface Mamdani type method will be added to the previously established model. This model will give us good opportunity to discuss the advantage and disadvantage of fuzzy control method different types, this work will focus on adding and discussing one method.*

**Keywords:** Control model; milling machining; Matlab/Simulink; Fuzzy controller

## 1. Introduction

There is [1] a variety of reasons for the installation of a monitoring system in a manufacturing process. Modern manufacturing equipment has to be flexible, sustainable and operative with minimum human interface, while machine tools have to operate free of errors. Two major problems in the field of metal cutting are tool wear and tool breakage. Number of schemes, techniques and paradigms have been used for the development of functional decision making systems that would derive a conclusion on machining process conditions, based on sensor signals [2-4]. The cognitive paradigms most frequently employed for the purpose of monitoring in machining, are the Neural Networks (NN) and Fuzzy Logic (FL). With the rapid development of fuzzy technologies, a lot of research has been done, different fuzzy control strategies have developed based on different methods, such as PID-fuzzy control [5], sliding mode fuzzy control [6], neural fuzzy control, adaptive fuzzy control and phase-plane mapping method fuzzy control [7]. Fuzzy inference is the process of formulating the mapping from a given input to an output using FL. There are two types of fuzzy inference systems namely that are Mamdani-type and Sugeno-type [8]. Mamdani method was among the first control systems built using fuzzy set theory. It was proposed in 1975 [9 and 10] as an attempt to control a steam engine and boiler combination. Mamdani style inference expects the output membership functions to be fuzzy sets. Mamdani style inference expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs

defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership functions rather than a distributed fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required to find the centroid of a two-dimensional shape. In this paper, a milling process will be created in easy way, using the mathematical logic of milling machining process to do the analysis.

## 2. Machining Process Control Model

There are various numbers of modeling methods to predict the machining process from the cutting force effects point of view, such as FEM modeling, modeling geometric Raito of the engagement of the cutting tool [11-13]. Before we can control a system we must understand in mathematical terms how the system behaves without control [14]. Milling is one of the most well-known material removal techniques, where material is removed from work piece using rotating cutter [15]. According to the cutting logic, let us establish the model as following:

### 2.1. Machining Process Control Model

The process includes feed rate and cutting forces model.

**2.1.1. Machining process model:** Feed rate  $f$  (mm/min) a milling-tool moves through the material being cut, this calculated using the feed per tooth  $f_z$  (mm/teeth),  $N$  (tooth) is the number of cutting teeth on the tool, and  $n$  represents the angular velocity of the spindle (rev/min), The calculation of this formula will be:

$$f = n \times f_z \times N \quad (1)$$

Let us change the feed rate units form (mm/min) to (mm/sec)

$$f = n \times f_z \times N / 60 \quad (2)$$

### 2.1.2. Cutting Forces Model

It is well known that cutting forces are directly proportional to the chip area behavior [16- 18]. A simplified orthogonal cutting force has been introduced in [12] to model the dynamics of the forces in the cutting process. The cutting forces  $F_c$  that are expressed in Formula (3) composed of the specific cutting force  $K_c$  ( $N/mm^2$ ), axial cutting depth  $a_p$  (mm) and the feed rate  $f$  (mm/min) indexed to the exponent of the specific  $m$ .

$$F_c = K_c \times a_p \times f_z^m = (K_c \times a_p \times f_z^{m-1}) f_z \quad (3)$$

The actual cutting force  $F$  which is orthogonal and proportional to the tangential force can be described by following formula:

$$F = K_e \times F_c \quad (4)$$

Where,  $K_e$  is the actual specific cutting force gain.

## 2.2. The Servo System Model

The basic form of a DC servo system is made by an electronic motor with an output shaft that has an inertial load  $J$  on it, and friction in the bearings of the motor and load (represent by the constant  $b$ ), there will be an electrical drive circuit where input voltage  $u$  (t) is transforming the motor into a torque  $T$  (t) in the motor output shaft [14]. Using system modelling ideas for mechanical systems a torque balance can be written between the input torque from the motor and the torque required to accelerate the load overcome friction.

$$J\ddot{\theta} + b\dot{\theta} = T(t) \quad (5)$$

Where  $\theta$  is the angular position of the servo output shaft, the control objective is control the shaft position  $\theta$  or the shaft velocity  $\dot{\theta}$  to be some desire value. The input voltage  $u(t)$  is related to the torque  $T(t)$  by the gain  $K_n$  and the inertia divided by the friction coefficient is referred to the as the system time constant  $\tau$ , where,  $\tau=J/b$ , so the system model becomes:

$$\tau\ddot{\theta} + \dot{\theta} = K_n u(t) \quad (6)$$

The standard form of the transfer function of a second –order system is:

$$G(s) = \frac{Y(s)}{U(s)} = \frac{K_n \omega_n^2}{s^2 + 2\zeta\omega_n + \omega_n^2} \quad (7)$$

Where  $Y(s)$  and  $U(s)$  are the Laplace transforms of the output and input variables, respectively,  $\omega_n$  is natural frequency, and  $\zeta$  is damping ratio. According to the mechanism of the milling model system, input and output of the servo will be as a fellow:

$$G(s) = \frac{f_z(s)}{u(s)} = \frac{K_n \omega_n^2}{s^2 + 2\zeta\omega_n + \omega_n^2} \quad (8)$$

### 3. Machining Control Model Transfer Function Blocks

According to formula (2), (3), (4) and (8), we can establish the model as shown in Figure 1.

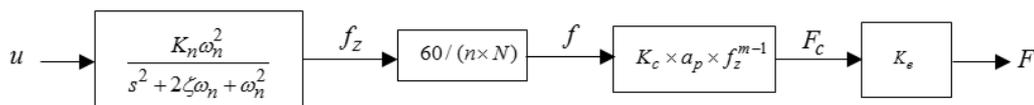


Figure 1. The Block Diagram of the System

The DC gain of the programmed system is :

$$K = \frac{60 \times K_n K_c K_e a_p f_z^{m-1}}{n \times N} \quad (9)$$

### 4. Machining Control Model System Simulation

In the present work, Matlab and Matlab/Simulink model has been developed to generate the model's transfer function to test the step response under various parameters. The simulation parameters are shown in Table 1.

Table 1. Input Simulation Parameters

Parameter	Sample	Value	Unit
Spindle speed	$n$	600	rev/min
Servo gain	$k_n$	1	mm/(V.s)
Specific cutting force	$K_c$	1760	N/mm <sup>2</sup>
Axial cutting depth	$a_p$	2	mm
Damping ratio (zeta)	$\zeta$	0.5	
Number of teeth	$N$	4	teeth
Natural frequency	$\omega_n$	20	rad/sec
Exponent of the specific	$m$	0.7	
Specific actual cutting force	$K_e$	2	N/mm <sup>2</sup>

#### 4.1. The Matlab Simulation

Matlab software able to create a continuous time transfer function with numerator and denominator specified by *num* and *den*. Step response is dynamic response of the system (assuming zero initial conditions) when the input is step function  $u(t) = 1, t \geq 0$ . In order to obtain the step response of the system, the command step is use with it is variations. According to Table 1 parameters Matlab code used to find out the impact of the exponent of the specific  $m$ , damping ratio  $\zeta$  and natural frequency  $\omega_n$  as:

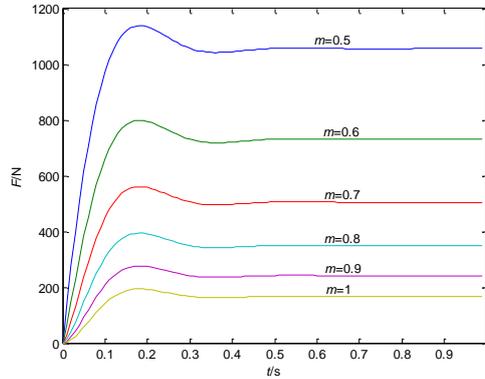


Figure 2. The Impact of Exponent of the Specific  $m$

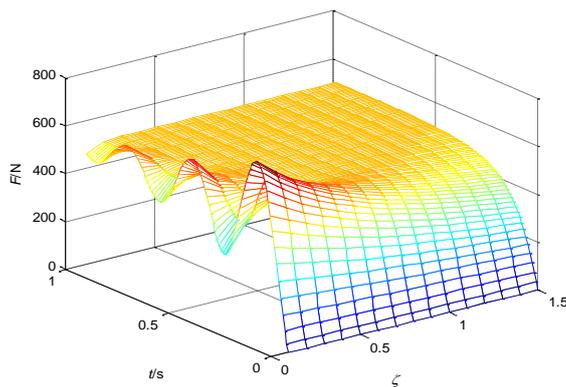


Figure 3. The Effect of Damping Ratio  $\zeta$

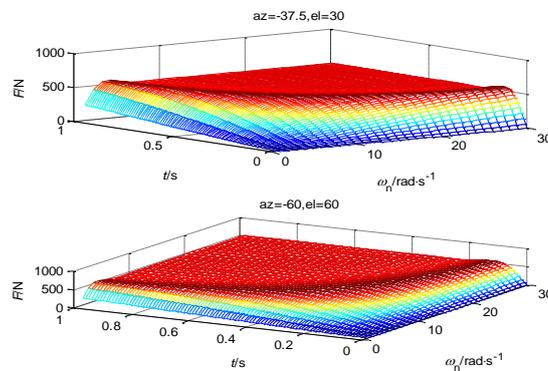


Figure 4. The Effect of Natural Frequency  $\omega_n$

## 4.2. Simulink Model

All equation symbols must be defined in a clear and understandable way. Simulink developed by the Math Works, is a commercial tool for modeling, simulating and analyzing dynamic systems, and it's widely used in control theory. In the present work, Simulink model has been developed to generate the model. The Simulink toolbox is used to simulate the orthogonal milling control process considering the dynamic equation developed in the previous section. The Simulink simulation model shown in Figure 5.

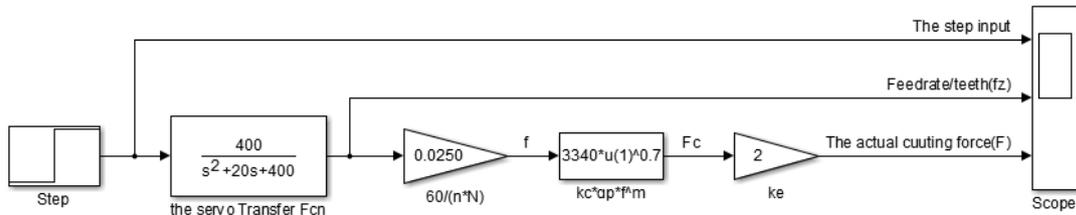


Figure 5. Simulink Model

The simulation parameters mentioned in Table 1, where the cutting process is active at  $t=5$  sec.

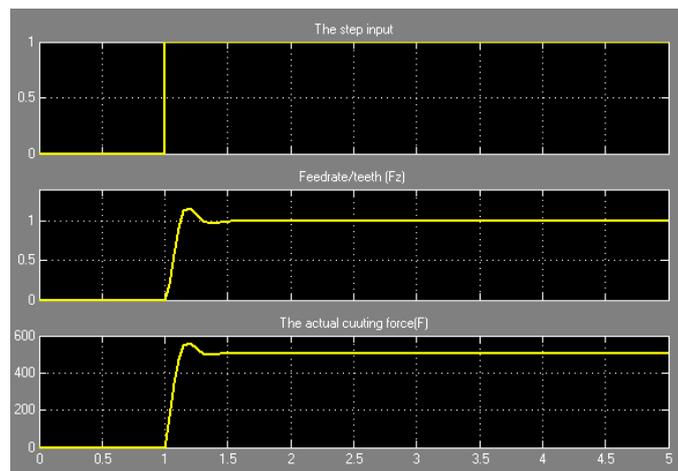
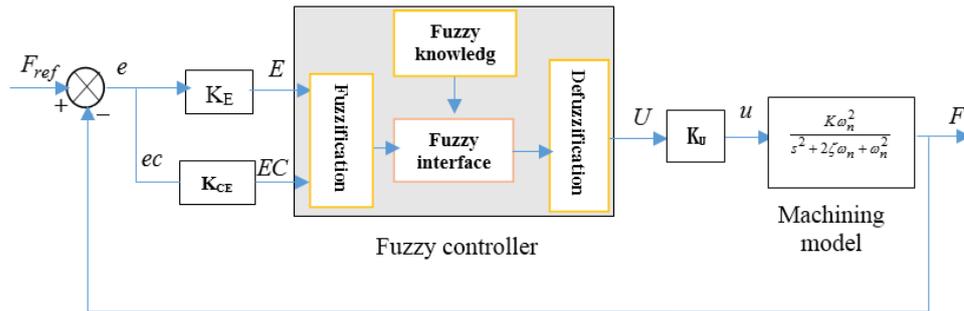


Figure 6. The Model Simulation

The output of this open loop model is the actual cutting force and according to the above Matlab three figures simulation the maximum value of the actual cutting force is similar with Simulink result. Now let's consider the model is active and correct.

## 5. Adding Fuzzy Controller

By using the same logic of fuzzy controller mentioned in [19 and 20], then add the established milling machining system model. Figure 7 is a typical two-input and single-output schematic diagram based on the Fuzzy control logic. Controller's input linguistic variables are the difference between reference forces  $F_{ref}$  and actual cutting forces  $F$  and the change rate of the deviation, the output linguistic variable is per/tooth feed  $f_z$ ,  $e$  is a deviation between an expectable value and the actual value,  $ec$  is the change rate of deviation,  $E$  and  $CE$  are fuzzy controller input values,  $KE$  and  $K_{CE}$  are quantitative factors and  $KU$  is the proportional output factor.



**Figure 7. Milling Machining Control Schematic Based On Fuzzy Control**

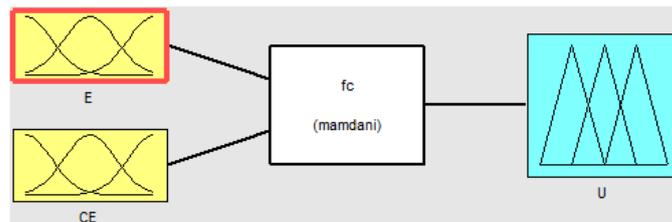
For, the deviation use the following equation:

$$e(i) = F(i) - F_{ref}(i) \quad (10)$$

$$e(i) = [e(i) - e(i-1)] / dt \quad (11)$$

## 6. Matlab Fuzzy Interface Method

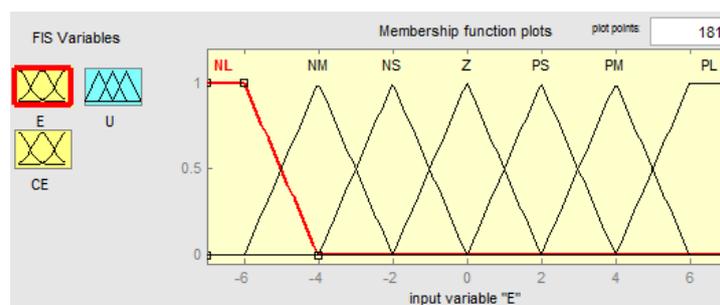
With the fuzzy interface engine, the rules combined the membership degree of fuzzy inputs determine the fuzzy outs put [6]. By using the Matlab fuzzy interface based on Mamdani –type implication.



**Figure 8. Fuzzy Interface Method Mandani Type Inputs and Output Variables**

### 6.1. Membership Function

By using the method of triangle membership function, the input and output variables have been fuzzily transformed as shown in Figure 9. Variables are subordinated the following fuzzy subset are: [NL, NM, NS, Z, PS, PM, PL], which donate negative large (NL), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM), positive large (PL). Let us consider the Error rang of the system is [-6, 6] with membership  $\mu$  [0, 1], so the discrete domain of  $E(i)$ ,  $EC(i)$  and  $U(i)$  will be: [-6, -5, -4, -3, -2, -1, 0, +1, +2, +3, +4, +5, +6].



**Figure 9. Subordinating Degree Function of Input and Output Variables**

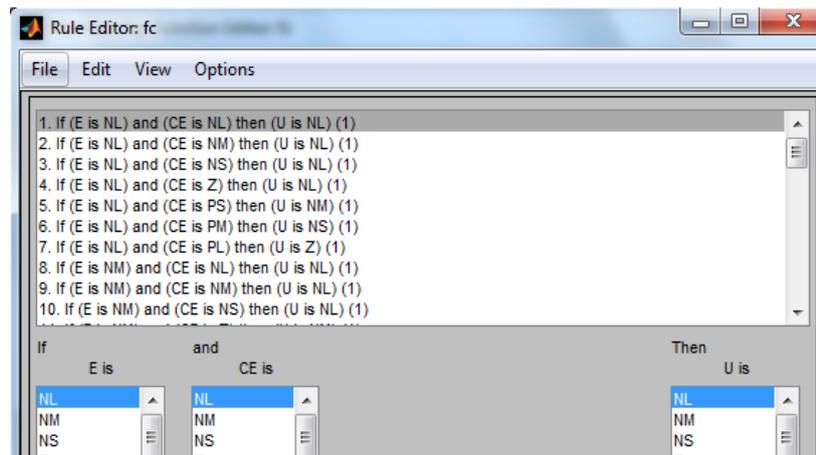
## 6.2. Control Rules

According to this article, there are seven fuzzy sets associated with seven sets of fuzzy quantities for either power error or error change. Each combination of a power error fuzzy set and a power change fuzzy set requires a control action. The rules can be described as “if E and EC then U”. The situation and corresponding control strategies are summarize as Table 2:

**Table 2. Rules for Fuzzy Control**

<i>E</i>	NL	NM	NS	z	PS	PM	PL
<i>CE</i>							
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NL	NL	NM	NS	Z	PS
NS	NL	NL	NM	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PS
PS	NM	NS	Z	PS	PM	PL	PS
PM	NS	Z	PS	PM	PL	PL	PS
PL	Z	PS	PM	PL	PL	PL	PS

After determine the fuzzy rules that expertise for the two dimensional control structure and the corresponding input fuzzy sets, we can make 49 fuzzy control rules as shown in figure 10.



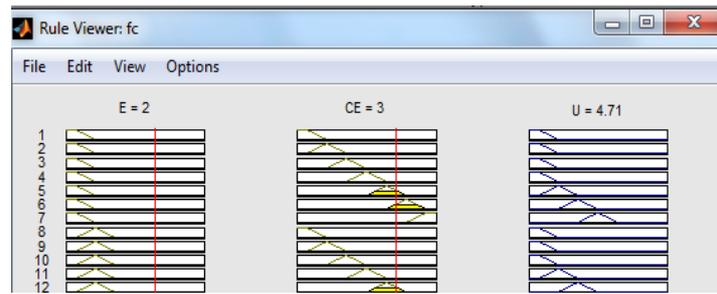
**Figure 10. Control Rules Editor Window**

## 6.3. Defuzzification

Defuzzification is the conversion of a fuzzy quantity to a precise quantity, fuzzification that is the conversion of a precise quantity to a fuzzy quantity. It has been proposed by investigators in recent years, among popular for defuzzification methods: centroid, bisector, Mean of Maximum (mom), Largest of Maximum (lom) and Smallest of Maximum (som). To give more reliable results, Centroid of area defuzzification method is used calculate the script any additional blank lines between paragraphs.

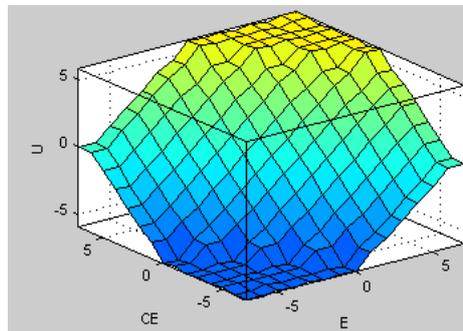
## 6.4. Fuzzy Interface System Verification

Through the above four steps, fuzzy interface system is created. To simulate and view the results, rules viewer and surface viewer are used. Figure 11 shows the rule viewer, where sets of membership function for particular two input *E* and *CE*, then one output *U*.

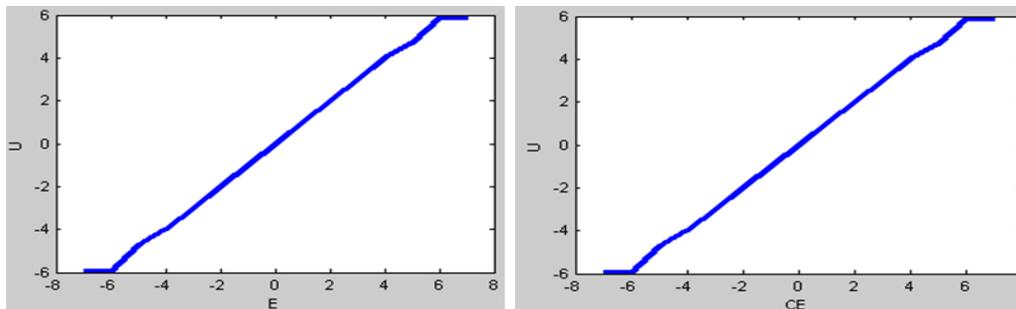


**Figure 11. Rule Viewer Window**

Another way to look at fuzzy logic system is surface viewer method figure 12 and 13, where control rules surface in 3D and 2 D. For Example:



**Figure 12. Control Rules Surface 3D**



**Figure 13. Control Rules Surface 2D**

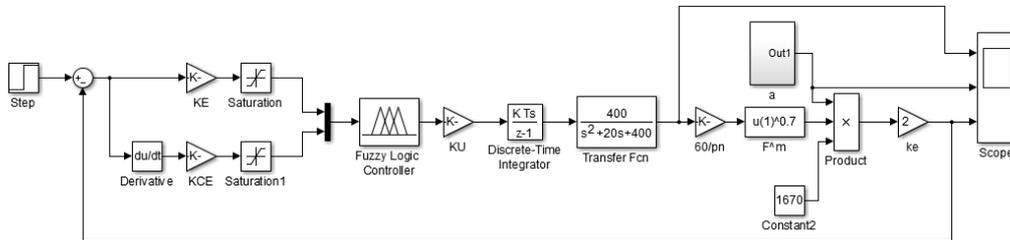
## 7. The Final Simulink Model of the Whole System

Assume a milling machining work piece with three value depth of cut 1, 2, 3 as shown in figure 15. The bottom of work piece considered as a reference of axial cutting depth, the top is 1, the middle edge is 2 and the end is 3.



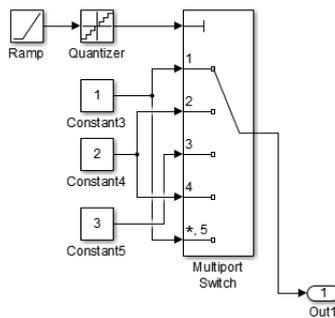
**Figure 14. The Work Piece Axial Cutting Depth**

In order to generate the Fuzzy model transfer function to test the step response under various parameters, where the simulation parameters Table 1. Fuzzy interface method Mamdani type control system of Matlab/Simulink simulation model diagram is established, Figure 15.



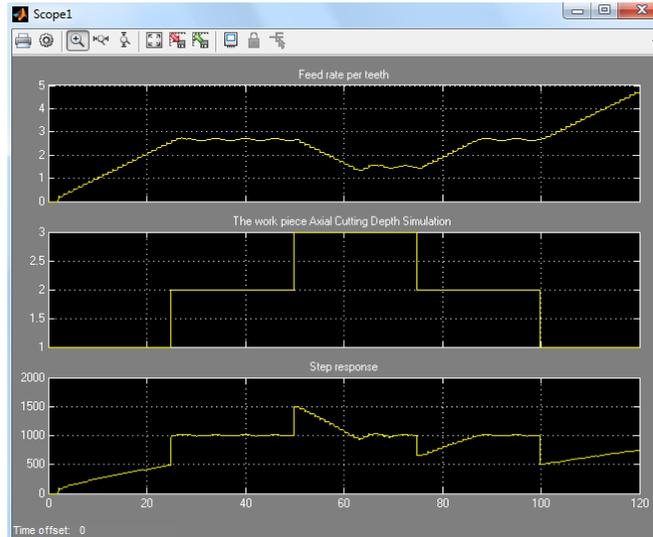
**Figure 15. Simulation Block Diagram of Fuzzy Interface Control in Matlab/Simulink**

A Subsystem module established to achieve the change rule of cutting depth, as shown in equire 16, oblique wave output ramp is quantitatively outputted by the module Quantizer, the three cutting depth corresponding value is 1 mm, 2 mm and 3mm. When Multiport Switch port value is 1, the value of Constant 3 is outputted from the first input port to the output port. The rest is similar. Setting the Multiport Switch time, can be realized input different cutting depth at different times.



**Figure 16. The Subsystem of Cutting Depth Step Change (a)**

For the simulation set  $KE$  gain to 0.1,  $K_{CE}$  to 0.01, saturation limited (-6.6),  $KU$  to 0.035, the step block final value to 1000N and the cutting process is active at  $t = 120$  sec.



**Figure 17. The Simulation Result**

All though this method is more logic able, easy to determine the input and the output by using rule viewer, but the main problem of this work is the simulation. The simulation process is too slow and need to wait more time. Because of this problem I will consider this method is not the best and I need to find another method for more fast simulation results.

## 8. Summary

A milling control model has been developed by using cutting parameters and simulated in Matlab/Simulink as an open loop transfer function , to make the model is comparable Matlab simulation is done to find out the impact of the exponent of the specific  $m$ , damping ratio  $\zeta$  and natural frequency  $\omega_n$ . Secondly the equation of milling process and servo system is establish, Simulink model is built and simulated ,the simulation result is comparable. Then, Matlab fuzzy interface based on Mamdani –type implication is established, to simulate and view the results, rules viewer and surface viewer are used. Next, Matlab/ Simulink model is establish according to logic of milling machining control Schematic Based On Fuzzy Control, the Matlab fuzzy interface based on Mamdani –type is added to the model through the Simulink fuzzy logic controller).by using the same parameters the model is simulated to find out the step response, finally, the advantage and dis advantage of this method are discussed.

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