Abstract – Universal Stretch and Bending Machine (USBM) is a combination of Stretch Machine and Bending Machine which are used in car door sash production. The main purpose of combining these two machines is to reduce the number of machines, space utilization and increase productivity. This paper basically focuses on the design and modeling for revolute control of USBM simplified model. Basically, comparative evaluation of intelligent control (Fuzzy Logic Controller) systems that suites the USBM simplified model are evaluated. The evaluation is done by comparing the PD–type FLC performance of different fuzzy rules and membership functions in terms of time response and integral square error. Prior to that, mathematical model of the system is first derived and verified by SIMULINK (MATLAB). Based on the simulation result, PD-type FLC with 5 membership function is better than PD-type FLC with 7 membership function in terms of time response specifications and integral square error.

Key-words: Universal Stretch Bending Machine, PD-type Fuzzy Logic Controller, Servomotor.

I. INTRODUCTION

In recent car door sash production requires for both stretch and bending machines. In minimizing the usage of two machines and by combining them into a single machine but with two functions as before, this could lead to space utilization and increase productivity. The Universal Stretch and Bending Machine comprises of prismatic and revolute movements. The studies for these movements are conducted individually on the simplified model for choosing the controller that best suites the design requirement before it can be implemented on the prototype machine. In recent years, the CNC controller [1]-[2] is still used in controlling machine and much more can be explored to improve its performance.

The objective of this paper is to study and compare the PD-type FLC performance of different fuzzy rules and membership functions on revolute control of USBM simplified model in terms of its time response specifications and integral square error.

Designing the Fuzzy Logic Controller, on the other hand, does not require for prior knowledge on system characteristic equation. The so called intelligent controller function is much closer in spirit to human thinking and natural language than traditional logical system where it provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy [3]. The implementation of Fuzzy Logic Controller in [4] using microcontroller proves the robustness of this controller where the results for both simulation and experimental are identical with regard to the load mass change.

II. REVOLUTE MODEL

The revolute model for the USBM was adapted from the model of the DC servomotor. DC servomotor is chosen since it is easier to control where by changing the armature voltage or current, the position or the speed of the DC servomotor can be varied. Fig.1 below shows the schematic of the armature controlled DC servomotor with a fixed field circuit. For transfer function derivation, this system was divided into three major components of equation, which are electrical equation, mechanical equation, and electromechanical equation [5].

The electrical equation for DC servomotor system could simply be obtained based on the Kirchoffs Voltage Law as follows:

\[ e_a(t) = R_a i_a(t) + L_a \frac{di_a}{dt} + v_b(t) \]  

(1)

or in frequency domain

\[ E_a(s) = (R_a + sL_a)i_a + V_b(s) \]

(2)

where \( e_a \) and \( i_a \) are the armature voltage and current respectively, \( R_a \) is the armature resistance, and \( L_a \) is the armature inductance. The back emf, \( v_b \), on the other hand, induced by the angular speed of the motor shaft, such that

\[ V_b(s) = k_b \omega_m(s) = k_b \theta_m(s) \]

(3)

where \( k_b \) is the back-emf constant, \( \omega_m \) is the angular speed, and \( \theta_m \) is the angular displacement.

Next, the mechanical equation can be obtained as follows:

\[ \tau_m(t) = J_m \frac{d^2 \theta_m}{dt^2} + D_m \frac{d\theta_m}{dt} \]

(4)

or in frequency domain
\[ \tau_m(s) = (s^2 J_m + s D_m) \theta(s) \]  

(5)

where \( \tau_m \) is the equivalent torque produced by the servomotor shaft, with \( J_m \) and \( D_m \) as the equivalent inertia and equivalent viscous density by the DC servomotor respectively.

The electromechanical equation of the DC servomotor was related with the equivalent torque produced by the motor shaft is basically proportional to the multiplication of armature current with a motor torque constant, or

\[ \tau_m = k_t I_a \]  

(6)

From (1) to (6), the frequency domain open loop block diagram for the schematic in Fig. 1 is obtained and shown as in Fig. 2.

By substituting (4) into (6), it could be obtained that

\[ x_1(t) = \frac{1}{D_m J_m} x_2(t) - \frac{1}{J_m} x_3(t) \]  

(11)

Therefore, the state-space representation of DC servomotor in space matrix could be expressed in this form:

\[
\begin{bmatrix}
\dot{x}_1(t) \\
\dot{x}_2(t) \\
\dot{x}_3(t)
\end{bmatrix} =
\begin{bmatrix}
-k_t & 0 & 1 \\
\frac{R_a}{L_a} & 0 & 0 \\
\frac{1}{J_m} & 0 & 0
\end{bmatrix}
\begin{bmatrix}
x_1(t) \\
x_2(t) \\
x_3(t)
\end{bmatrix} +
\begin{bmatrix}
0 \\
1 \\
0
\end{bmatrix} e_a(t)  
\]  

(12)

and

\[
y(t) =
\begin{bmatrix}
x_1(t) \\
x_2(t) \\
x_3(t)
\end{bmatrix}  
\]  

(13)

IV. FUZZY LOGIC CONTROLLER

Fuzzy Logic Controller has emerged as one of the most active and fruitful research areas in the application of fuzzy set theory, fuzzy logic and fuzzy reasoning. In contrast to conventional control techniques, fuzzy logic control is best utilized in complex ill-defined processes that can be controlled by a skilled human operator e.g. complex chemical plant without much knowledge of their underlying dynamics [3]. Generally, Fuzzy Logic Controller comprises of four principal components [6]:

- fuzzifier
- knowledge base
- inference engine
- defuzzifier

The component of the Fuzzy Logic Controller can be clearly seen based in Fig.3 below:

Through several observations the input and output fuzzy variables has been identified in Table 1 below.
TABLE 1. Input and output of fuzzy variables

<table>
<thead>
<tr>
<th>No</th>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Error voltage between the actual and desired angular position. (e)</td>
<td>Control action to the system plant (Δu)</td>
</tr>
<tr>
<td>2</td>
<td>The change of error voltage between the actual and desired angular position. (Δe)</td>
<td></td>
</tr>
</tbody>
</table>

A PD-type fuzzy logic controller utilizing angular position error and derivative of angular position error is developed to control the DC motor system. The hybrid fuzzy control system proposed in this work is shown in Fig. 4, where \( r(s) \) and \( \theta(s) \) are the desired angle and angular position of the DC motor, whereas \( k_1, k_2 \), and \( k_3 \) are scaling factors for two inputs and one output of the fuzzy logic controller used with the normalised universe of discourse for the fuzzy membership functions.

![Fig.4. PD-type FLC control structure](image)

In this paper, triangular membership functions are chosen for angular position error, derivative of angular position error, and control voltage with 50% overlap. Normalized universes of discourse are used for both angular position error and its derivative and control voltage. Scaling factors \( k_1 \) and \( k_2 \) are chosen in such a way as to convert the two inputs within the universe of discourse and activate the rule base effectively, whereas \( k_3 \) is selected such that it activates the system to generate the desired output. Initially all these scaling factors are chosen based on trial and error. To construct a rule base, the angle error, angle error derivative, and torque input are partitioned into five and seven primary fuzzy sets for five and seven membership functions respectively as shown below

\[
\text{Angle error (e)} = \{\text{NM, NS, ZE, PS, PM}\} \\
\text{Angle error derivative (}\Delta e\text{)} = \{\text{NB, NM, NS, ZE, PS, PM, PB}\} \\
\text{Torque (}\Delta u\text{)} = \{\text{NM, NS, ZE, PS, PM}\} \\
= \{\text{NB, NM, NS, ZE, PS, PM, PB}\}
\]

where

\[
\begin{align*}
\text{NM} &= \text{Negative Medium}, \\
\text{NS} &= \text{Negative Small}, \\
\text{ZE} &= \text{Zero}, \\
\text{PS} &= \text{Positive Small}, \\
\text{PM} &= \text{Positive Medium}
\end{align*}
\]

Table 2 and 3 show the rules for five and seven membership functions respectively. It is noted that, 11 rules is needed to compute the rules for five membership functions while 35 rules is required for seven membership functions. In this study, the conditions of error (e), the rate of change of error (Δe) and the output which is the change in the control signal (Δu) are formulated based on the underdamped system response behaviour. The control surface for both types of membership functions is shown in Fig. 5 and 6. Next, max-min composition technique is used as the fuzzy inference method [4]. Centroid defuzzification technique is used for defuzzification process as this method is the most prevalent and physically appealing of all defuzzification methods.

The three scaling factors, \( k_1, k_2 \), and \( k_3 \) for both type of membership functions were chosen heuristically to achieve a satisfactory set of time domain parameters. For five membership functions these values were recorded as, \( k_1 = 0.2 \) \( k_2 = 0.012 \) and \( k_3 = -10 \) while for seven membership functions these values were recorded as, \( k_1 = 0.22 \) \( k_2 = 0.05 \) and \( k_3 = 3.4 \).

![Fig.5. Surface PD-type FLC with 5 MFs.](image)
V. SIMULATION RESULTS

Fig. 7 shows the angular displacement response of DC servomotor using PD-type FLC with 5 MFs and 7 MFs. It is noted that both controllers can track the step input response of 5 degree. However, PD-type FLC with 5 MFs shows a better performance in terms of time response specifications and integral square error as compared to the PD-type FLC with 7 MFs controller. For the time response performance, the PD-type FLC with 5 MFs produce settling time and rise time of 0.247 s and 0.156 s respectively whereas the PD-type FLC with 7 MFs produce settling time and rise time of 0.298 s and 0.184 s respectively. It shows that the PD-type FLC with 35 rules and 7 MFs results in a slower response as compared to PD-type FLC with 11 rules and 5 MFs. It can be said that with higher number of rules the complexity to compute the rules will increase and affect the speed of the response. In term of integral square error, the PD-type FLC with 5 MFs results in twice less of ISE as compared to the PD-type FLC with 7 MFs with the value of 1.755 and 3.515 respectively. The comparative assessment of both controllers is summarized in Table 4.

VI. CONCLUSION

The performance between PD-type FLC with 5 MFs controller and PD-type FLC with 7 MFs controller are analyzed in terms of time response specifications and integral square error. Based on the simulation result, it can be concluded that PD-type FLC with 5 MFs controller exhibits better performance compared to PD-type FLC with 7 MFs controller in terms of time response specifications and integral square error. The complexity to compute the rules will increase and affect the speed of the response as the number of rules and membership functions are increased. PD-type FLC with 5 MFs produces a high speed operation of DC motor which is important in operating the bending and stretching process.
VII. ACKNOWLEDGEMENT

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VIII. REFERENCES


IX. BIOGRAPHIES

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