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# Auto-Tuning PI Controller Design Using Fuzzy Logic Controller for Web Tension Control in Roll Rewinder System

Ahmad Faizal[1], Rahmadeni[2] , Elfira Safitri[3], Juliesty Huswina[4], Rudy Kurniawan[5]
[1,4]Electrical Engineering Department, Faculty of Science and Technology, UIN Sultan Syarif Kasim Riau, 28129, Pekanbaru, Indonesia
[2,3]Mathematics Department, Faculty of Science and Technology, UIN Sultan Syarif Kasim Riau, 28129, Pekanbaru, Indonesia
[5]Electrical Engineering Department, Faculty of Engineering, Bangka Belitung University, Kep. Bangka Belitung, Indonesia

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**ABSTRACT**

Paper has a very important role, because it increases the productivity of pulp and paper companies in Indonesia. The company's development in 2018 increased by 2.1%, this was indicated by increasing consumer demand. Therefore, paper becomes a necessity in everyday life. The criteria for the paper to be produced are paper with a flat surface and cannot be wrinkled. However, errors in paper production that often occur are a lot of wrinkles and uneven paper surfaces. This happens because of a discrepancy in the dynamics of paper tension with the standards that have been set. The paper record is caused by the dynamics of the web tension in the Rewinder Roll system. In order for the web tension to remain stable, a controller is needed. The controller used is Auto-Tuning PI controller using Fuzzy Logic Controller (FLC). The controller can be said to be successful when it is able to perform automatic tuning of setpoint changes. The results showed that the system was able to achieve setpoint values, overcome overshoot and steady-state error (Ess) with response time values, namely Tr=0.3151 seconds, Ts=0.3750, Td=0.0721, overshoot=0.0044%, and Ess=0 N.



**Corresponding Author**:

Ahmad Faizal
Electrical Engineering Department, Faculty of Science and Technology
UIN Sultan Syarif Kasim Riau, 28129, Pekanbaru
Email: ahmad.faizal@uin-suska.ac.id

## 1. INTRODUCTION

In our life, paper has a very important role [1]. Even though the technology is now completely online, it does not reduce the need for paper use, it actually increases the productivity of pulp and paper companies in Indonesia [2]. This productivity is balanced with the great human needs and the rather rapid competition of the paper industry [3]. The development of pulp and paper companies in Indonesia in 2018 increased by 2.1%, this is indicated by increasing consumer demand [4]. Indonesia is ranked 9th for pulp and paper production in the world. Pulp output reached 4.55 million tons and paper production was 7.98 million tons [2]. In terms of exports, Indonesia can export 3.75 million tons of pulp worth US$1.85 billion and 4.26 million tons of paper worth US$3.76 billion. The European Union, the United States and China are the leading export providers for the pulp and paper industry.

With the increasing growth and development of the paper industry, the quality of the paper produced must also be improved, because in an industry quality is the main thing [5]. In addition, controlling the quality of the products produced must also be considered and anticipatory action is needed against errors that may arise during the production process [6]. In this case, the criteria for the

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paper to be produced are paper with a flat surface quality and no wrinkles. However, based on several studies that have been carried out, errors in paper production that often occur are precisely the number of wrinkles and uneven paper surfaces [5,7]. This happens because of a discrepancy in the dynamics of the paper tension with the standards that have been set [8].

Sheet stress or web stress comes from the word web, which means the production material is pulled from the roll repeatedly, stress refers to the measured tensile strength stretched on the web [8]. The intended production material is paper, where before being rolled the paper has been dried which will later go through the printing process [9]. It can be concluded that web tension is a control of paper tension with the aim that the paper produced has a flat surface and the roll becomes solid. With this control will produce quality paper and errors / defects on the paper can be reduced [8].
In order for the quality of paper production to be stable, it is necessary to have a controller to maintain its stability. [10]. Several studies have been conducted, such as the use of adaptive force control to control the web force, a Neuro-Fuzzy approximator controller used to schedule gain in the web handling control system.

The controller performance with setpoint gain between 0.1 and 0.2 can reach steady state within 6 seconds [11]. In addition, research on web tension uses an optimal LQR controller that is able to respond to changes in set point optimally with an overshoot of 0.05% and a steady state error of 0.0025N [12]. Web voltage control is also discussed in other studies, especially the performance of a powerful PID controller, the focus of this research is to compare the performance of conventional PID controllers and conventional PID controllers. As a result, the Robust PID controller has a better system response than the conventional PID controller, with an overshoot value of 1.744%, and there is no oscillation [13].

In addition, research is also conducted on the comparison of the performance of the Self-Adaptive PI controller using Fuzzy Logic Controller (FLC) with the PI controller to control the servo motor on the ball tracking system, the performance of the Self-Adaptive PI controller using FLC with overshoot on the servo tilt 22%, servo pan 10.8 %, while the PI controller with servo pan 19.8% and servo tilt 22.7% [14]. Furthermore, research on speed control of electric bicycles using self-tuning Fuzzy-PI controller with load and without load. For load performance, settling time (Ts) is 4.9 seconds, overshoot is 0%, and the error is steady at 0. While for no-load performance, settling time (Ts) is 6.9 seconds, overshoot is 9.3%, and Ess is 0 [15]. In this study, researchers will discuss FLC, which will then be combined into an auto-tuning PI controller using FLC. Fuzzy logic is an intelligent control system that imitates human thinking in decision making. The decision is based on an if-then (if-then) rule relationship [16]. A Fuzzy logic controller is equivalent to solving the problem of uncertainty in data by mapping the relationship between input and output. The controller has the ability to increase transient response, but is very sensitive to disturbance [17]. When combining the Auto-TuningPI controller using Fuzzy Logic Controller, the controller has proportional-integral parameters in the form of Kp and Ki values which are set using Fuzzy logic. For Fuzzy logic, the input is an error and a delta error, and the output is a value of Kp and K [18].

## 2. RESEARCH METHOD

### 2.1. Rewinder Roll

The rewinding roll is part of the cutter (coating). The coater contains two rolls, a reverse roll and a loose roll. Rolling rewinding is a paper rewinding (pulling) machine, while roller rewinding acts as a rewinding machine. After the drying process, the dry paper is rolled into a large roll (Jumbo Roll), which is then removed to be cut into small rolls [10].

### 2.2. Mathematical Model of Rewinder Roll System

Before modeling the mathematical equations of the system, the first step that must be done is to make an analogy or assumption about the web tension [13]:

1. Elastic paper,
2. Strain / $\varepsilon \ll 1$,
3. The transverse width of the paper is the same,
4. The acceleration of V1 on the lead roll is constant,
5. No change in paper density.

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$$\rho = \rho u + 1 \tag{1}$$

The paper dynamics modeling is:

$$\frac{d(\rho AL)}{dt} = \rho_1 A_1 V_1 - \rho AV \tag{2}$$

Information:
V = Speed
A = Surface area on a sheet of paper
$\rho$ = Resivitation (paper density)
L = Paper length

The stress on the plant is used the following Law of Elasticity:

$$\sigma = E\varepsilon + C\frac{dE}{dt}, \sigma = \frac{T}{A} \tag{3}$$

then using the equation below can determine the strain and continue mass:

$$\varepsilon = \frac{L - Lu}{Lu}, \rho AL = \rho u AuLu \tag{4}$$

Furthermore, using the simplification of equations 3 and 4 above, we get a way to find the characteristics of torque dynamics in the Rewinder Roll area, namely:

$$L\frac{dT}{dt} = EA(V - V_1) + CA\frac{d}{dt}(V - V_1) \tag{5}$$

Information:
L = Length between lead roll and Rewinder Roll
E = Young's Modulus of Elasticity on paper
A = Cross-sectional area of paper
V = Speed on Rewinder Roll
V1= Speed on lead roll
C = Paper damping modulus
ε = Strain on web tension
σ = Tension on web tension

So from equation 2.5 obtained the Laplace equation, namely:

$$\frac{T}{(V - V_1)} = \frac{\frac{CA}{L}s + \frac{EA}{L}}{s + \frac{V_1}{L}} EA(V - V_1) + CA\frac{d}{dt}(V - V_1) \tag{6}$$

Equation 2.6 above is modeling the dynamics of the domain of the rewinder region. Components such as gearbox, rewinder roll, and motor are omitted parts which are expressed in Newton's law into the equation:

$$\sum \tau(t) = J\alpha(t) \tag{7}$$

Information:
$\tau$ = Turning Moment or Torque
$J$ = Constant of Inertia
$\alpha$ = Rotation Acceleration

The rotary force or torque input (t) acting on a rotating mass having an inertia of mass J will cause a rotation with an angle of rotation $(t)$, with angular velocity and acceleration $(t)$ and $(t)$. In each viscous

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torsion friction ($t$), it causes the opposite torque rotational force due to the physical properties of the engine mass, with the equation:

$$\tau b(t) = B\omega(t) \tag{8}$$

Information:
$\tau_b$ = Twist Moment or Friction Torque
$B$ = Coefficient of Friction
$\omega$ = Rotation Speed

From equations 7 and 8, the Laplace equation is obtained as follows:

$$\frac{\omega t}{\tau} = \frac{1}{(Js + B)} \tag{9}$$

Furthermore, equations 2.6 and 2.9 are linearized in the following tension web block diagram:

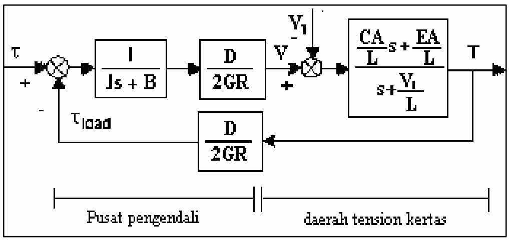


**Figure 1.** Rewinder roll circuit [13]

The second-order transfer function in the s-domain is obtained from the block diagram above starting from the motor torque to the tension of the sheet of paper, namely [13]:

$$\frac{T(s)}{\tau(s)} = \frac{\frac{DEA}{2GRJL}\left(\frac{C}{E}S+1\right)}{S^2+\left(\frac{B}{J}+\frac{V_1}{L}+\frac{D^2CA}{4GR^2JL}\right)S+\left(\frac{BV_1}{JL}+\frac{D^2EA}{4GR^2JL}\right)} \tag{10}$$

### 2.3 Auto-Tuning PI Controller using Fuzzy Logic Controller

Auto-Tuning PI controller using Fuzzy Logic Controller (FLC) is a controller based on the traditional PI controller structure. The PI controller parameters are pre-set using traditional tuning methods such as the Ziegler Nichols method [19]. The FLC structure used by the PI-Fuzzy controller is the same as the FLC structure, which consists of a Fuzzy interface, knowledge base, reasoning and non-Fuzzy interface. Each component function is described in detail in the Fuzzy logic description. Figure 1 shows the block diagram of the proposed PI-Fuzzy controller.

Figure 2 shows the input and output variables for each controller. For the FLC, the input variables are error (e) and the rate of change of error (ec or de/dt), and the output variables are Kp and Ki. The controller design adopts Si and Wang [20]. It includes Fuzzy sets, linguistic values, Fuzzy rules, and equations for calculating new values of Kp and Ki in the PI controller.

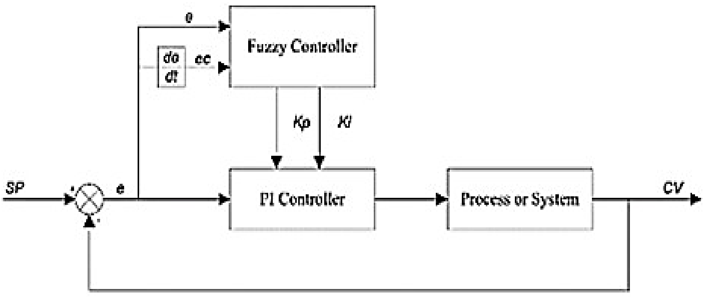


**Figure 2**. Auto-Tuning PI controller circuit using Fuzzy Logic Controller [19]

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### 2.4 Proportional Integral (PI)

The Proportional Integral controller is a combined control system between the Proportional controller and the Integral controller [21]. Proportional Integral controllers are widely used in industrial processes because they optimally solve problems that arise [18].

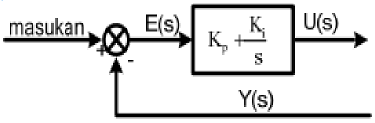


**Figure 3.** Integral Proportional control block diagram [22]

### 2.5 Close Loop System Testing

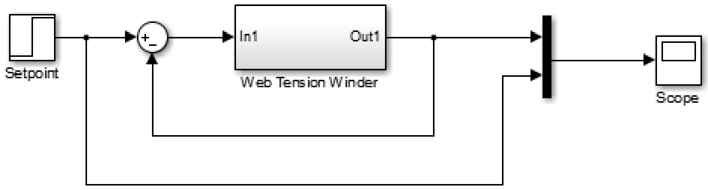


**Figure 5.** Close loop Simulink circuit

### 2.6 Tuning Kp and Ki Values

**Table 1.** Tuning Kp and Ki values

| **Heuristic Method Test** | | **Transient Response** | | |
|---|---|---|---|---|
| Kp | Ki | Rise Time | Overshoot % | Steady-State Error |
| 0.24147 | 1.6286 | 0.245s | 0 | 0 |
| 0.4848 | 2.7606 | 0.121s | 0.62 | 0.0001 |
| 0.32649 | 2.1696 | 0.172s | 0.188 | 0 |
| 0.36864 | 2.2958 | 0.157s | 0 | 0 |
| 0.30156 | 1.9063 | 0.1995s | 0 | 0 |
| 0.2046 | 1.431 | 0.287s | 0 | 0 |
| 0.18451 | 1.4064 | 0.291s | 0.472 | 0 |
| 0.31567 | 2.0102 | 0.186s | 0 | 0 |
| 0.27552 | 1.9198 | 0.201s | 0.315 | 0 |
| 0.3644 | 2.3568 | 0.154s | 0.387 | 0 |

Table 1. above is the determination of the values of Kp and Ki which was carried out using the heuristic method for ten times. From the table, the Kp value is 0.36864 and the Ki value is 2.2958 with system response results such as rise time (Tr) is 0 seconds, overshoot 0% and steady-state error (Ess) is 0. These values are chosen according to the output and transient response of the system which are better than other Kp and Ki values.

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### 2.7 Auto-Tuning PI Controller Design Using Fuzzy Logic Controller

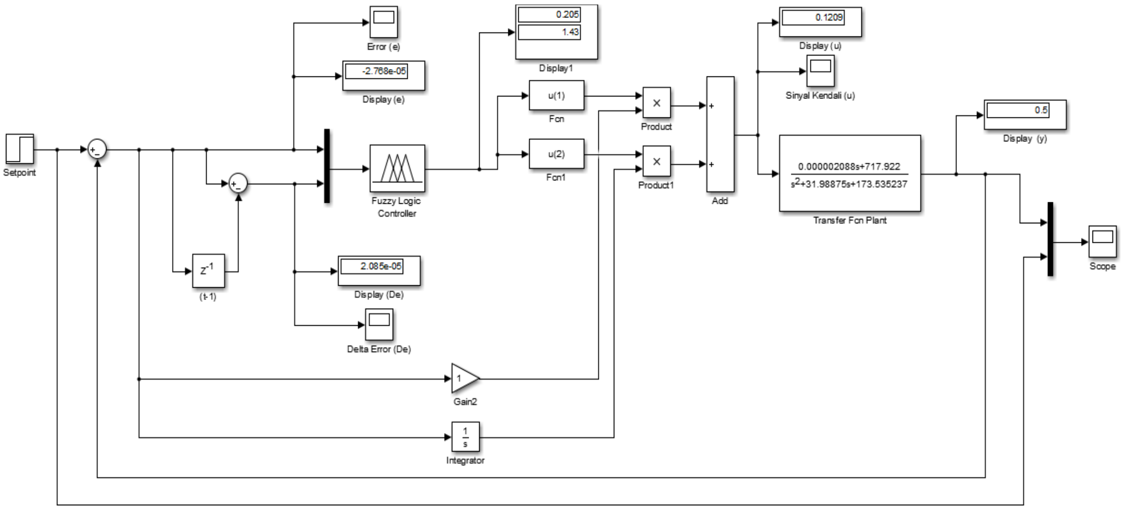

**Figure 6**. Auto-Tuning PI controller Simulink circuit using Fuzzy Logic Controller

In the picture above is the controller circuit that will be used. In FLC there are inputs and outputs in it, for the error and delta error values are input, while the values of Kp and Ki are Fuzzy outputs. Then, the linear interpolation method is used to find the value of the transient response after obtaining the Kp and Ki values that are relevant to the plant response.

## 3. RESULTS AND DISCUSSION

### 3.1 Analysis and Results of Web Tension Simulation on Close Loop Rewinder Roll System

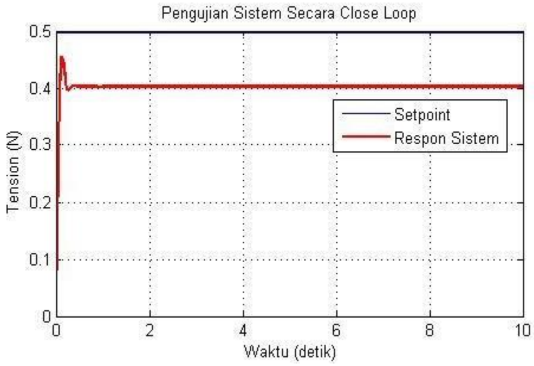


**Figure 7.** System response results in close loop

The results of the response of the web tension simulation in a close loop show that the set value is 0.5 N, but the system output shows that the value does not reach the set value, resulting in a steady-state error (Ess) of -0.0455N.

**Table 2.** System response results in close loop

| Response Analysis | Simulation Results |
|---|---|
| Rise Time (Rs) | -0.0127 detik |
| Settling Time (Ts) | 0 detik |
| Delay Time (Td) | 0.052 detik |
| Maximum Overshoot | -0.091 % |
| Steady-State Error (Ess) | -0.0974 N |

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This research is divided into several stages, namely the validation of the mathematical model of the roll rewinder system to analyze the results of the system response. The design of the Auto-Tuning PI controller uses Fuzzy Logic Controller (FLC), which is applied to the roller system by deriving the mathematical model of the controller. Furthermore, the simulation results from the validation of the system's mathematical model and the design results using the Auto-Tuning PI-Fuzzy controller. The performance of the reel winding system was analyzed using a Auto-Tuning PI-Fuzzy controller. Then the last conclusion.

### 3.2 Results and Analysis of Web Tension Testing on Rewinder Roll System with Auto-Tuning PI Controller Using Fuzzy Logic Controller

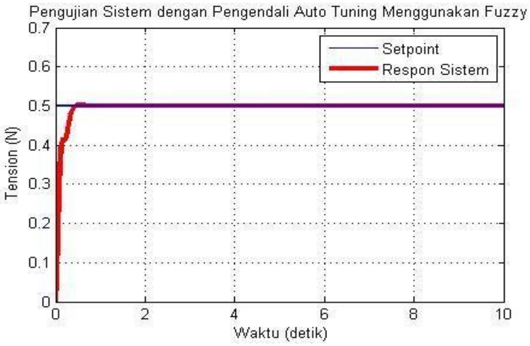


**Figure 8.** System response results with Auto-Tuning PI controller using FLC

Based on the picture above, it can be seen that the resulting system response has reached the specified set point with the simulation time used is 15 seconds.

**Table 3.** Results of system response with Auto-Tuning PI controller using Fuzzy Logic Controller

| Response Analysis | Simulation Results |
|---|---|
| Rise Time (Tr) | 0.3151 detik |
| Settling Time | 0.3750 detik |
| Delay time | 0.0721 detik |
| Maximum Overshoot | 0.0044% |
| Steady-State Error (Ess) | 0 N |

## 4. CONCLUSION

This study discusses testing the web tension on the Rewinder Roll system using the Auto-TuningPI controller using Fuzzy Logic Controller with the Fuzzy Mamdani method and the input values (error and delta error) in the form of Kp and Ki. After the test is carried out, the results show that the overshoot and the existing steady-state error (Ess) condition can be overcome. In addition, the performance of this controller can also be said to be good in overcoming the problems that exist in the Rewinder Roll system.

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