Winding Tension Control System Using PID-PLC Mechanism

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ABSTRACT: Tension parameter in winding system is essential to maintain the rolling process of two different spools. The reason is to have an optimum speed between the spool's motors to avoid a winding break-off, further damaging the end product. One of the techniques is by controlling the pendulum dancer position. In this case, a PID controller is designed to control the pendulum's position, and this is realized by integrating the Mitsubishi PLC module with an inverter speed. As a result, the pendulum dancer varying between 100° and 120° and is located at the second quadrant. The rise time to recover from a sudden fall is, on average, around 2.6 times faster than open-loop system performance.

Keywords: Winder tension system, pendulum dancer, PID controller, PLC module

1. INTRODUCTION

Winder system is widely applied in textiles, packaging and cable manufacturing [1-3]. It consists of two processes, which are known as unwinding and rewinding operations. The unwinding process draws the wire from a bigger coil diameter to a specific diameter required in the rewinding process. On the other hand, the rewinding process takes the wire into a particular spool diameter [3].

In the wire winding process, stable tension is one of the controlled parameters that determine the quality of the product [4]. During the operation of machines, the diameter of coiler in the unwinding process decreases, and the speed becomes faster. In the rewinding process, the speed also varies since the diameter of wire becomes larger. Incorrect tension will cause tension vibration [4], wire winding defect and straightness failure [3].

Therefore, the pendulum dancer technique is implemented to control the tension, especially at the intermediate and finishing drawing cable. The position of the pendulum dancer would be affected according to speed variation. As a result, by applying an angle potentiometer at the dancer with a correct motor speed adjustment, a closed-loop control between two motors could be created to control the wire tension system.

This paper focuses on applying Proportional Integral Derivative (PID) gains based on the proportional term (K_P), the integral term (K_I) and the derivative term (K_D) to control the position of the pendulum dancer. Then, a control signal is implemented in the Programmable Logic Controller (PLC) module to maintain the tension parameter that is further demonstrated from the variation of pendulum dancer movement. The PLC gives a command to the D700 Mitsubishi inverter to compensate for the speed in the unwinding motor. This strategy enables a faster rate of the motor when the dancer moves downward, and speed will significantly reduce when the pendulum dancer reaches the upper tension limit.

2. METHODOLOGY

The established winder tension physical model comprises two main spools for unwinding and rewinding processes. Both spools have their motor. Four rollers are attached to the system to reduce the cable's resistance and tension during the winding process. Figure 1 illustrates the physical model of the wire winding system, which is designed and developed at Motion Control Research Laboratory, Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM).

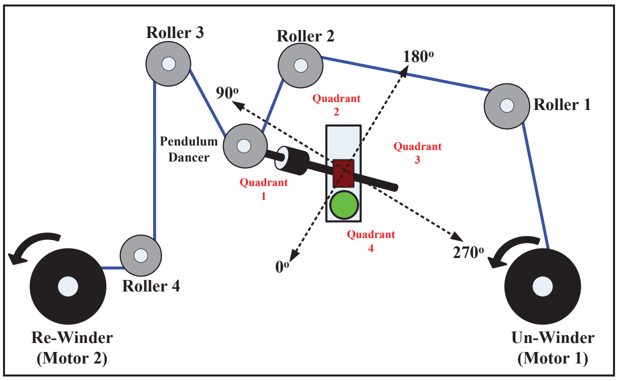

Figure 1: Physical model of a wire winding system.

As shown in Figure 1, the position of the pendulum dancer could be categorized into four quadrants. However, this paper only focuses on the pendulum dancer position from the first quadrant until the maximum limit in the second quadrant. Midori precision sensor is used to measure the position of the pendulum dancer and send feedback to the PID controller. At first, the pendulum dancer is let run in an open-loop without a controller to obtain the position transfer function using the System Identification tool from MATLAB software.

Then the transfer function is used to tune the PID gains. Next, PID gains compensate feedback and send the input to the PLC system. The D700 Mitsubishi inverter is used in assisting the PLC to increase and decrease the speed of the motor accordingly based on the signal received from the sensor. The motor would continuously run as long as the pendulum dancer is within an acceptable range and maintains the tension of wire in the winder system.

3. Results and Discussion

The open-loop configuration is set up by placing an empty spool in the rewinding motor and a wire spool in the unwinding motor. The wire is connected through the rollers, followed by the pendulum dancer ended at the rewinding spool. Both motors are allowed to run freely. The theoretical model of the tension system is explained in the previous paper [3]. The transfer function $G_P(s)$ is then obtained to represent the behaviour of the pendulum dancer position.

$$G_P(s) = \frac{0.5179s^2 + 0.01321s + 3.372e^{-6}}{s^2 + 0.01005s + 8.337e^{-5}}$$

During the open-loop responses, other parameters such as the force caused by the weight of pendulum dancer (F_W) and spring loading of the minimum dancer position (F_L) are not included in the simulation. In this simulation, the initial input is the torque of the motor, and the output is the position of pendulum dancer.

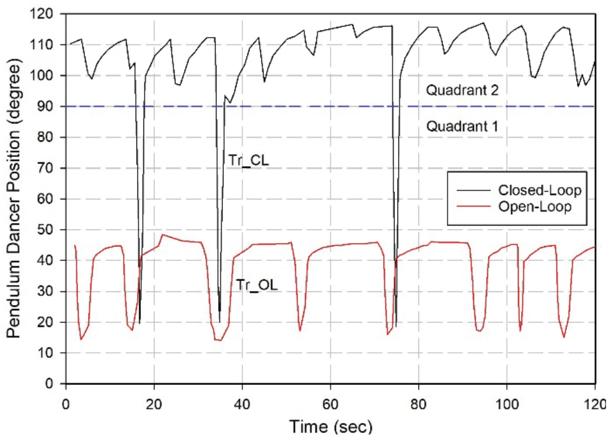

Figure 2: The angle variation of pendulum dancer in the open-loop and closed-loop system

Figure 2 shows the angle variation of pendulum dancers in the open-loop and closed-loop systems. From the figure, the red line demonstrates the open-loop response of the pendulum dancer. The position angle deviates from around 14° to 46° in the first quadrant. It could be considered as a significant variation and thus, unsuitable for the pendulum dancer movement. Besides, the average rising time (T_r_OL) to recover from the lowest position to 65% of the response is about 2.23 seconds.

This behavior is inappropriate for the tension performance in the winding system. Thus, to overcome this issue, PID gains are implemented in the closed-loop system. The setting parameters are listed in Table 1.

Table 1: Parameter settings in PLC Module

1.	K_P=0.00667, K_I=20s, K_D=10s, Set point=20
2.	Time = 160s
3.	Motor 1 = Pr.4 (20 Hz), Pr.5 (15 Hz), Pr.6 (10 Hz)

After applying the PID gains, the position angle rises into the second quadrant and remains consistent between 100° and 120°. Although the pendulum dancer falls a few times, the movement is fast-recovered to maintain the position angle above 100°. The average rising time for a closed-loop system (T_r_CL) to achieve 65% of the response from the lowest position is around 0.86 seconds. Thus, the movement of the pendulum dancer in Quadrant 2 is more consistent and reaches its stability after 80 seconds. The PID-PLC controller achieves significant tension improvement between the unwinding and rewinding processes. During a closed-loop experiment, only the speed of the unwinding motor is varied. Therefore, further investigation is required to evaluate the system when different rates are applied.

4. CONCLUSION

Realizing the PID controller in the PLC module enables the pendulum dancers to be maintained between 100° and 120°. The dancer's rise time at the closed-loop response is faster compared to the open-loop system. The result demonstrates that the mechanism is a less complex strategy to sustain tension parameters in a winding tension system. Thus, the PID-PLC control strategy has many potentials to explore further to enhance its performance.

5. ACKNOWLEDGEMENT

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