A Simulator of Winding Machine Controller using LabView Environment

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Abstract
Winding systems are major components in a wide variety of industrial factories for metal sheet or web conveyance, papermaking or polymer film extrusion processes. In those systems, it is clear that the quality of products and the performance of systems are determined by tension and velocity control of the moving material. Although the machine is classified as a nonlinear system typically, however; PID based controller are employed mostly in the industries. In this paper, based on a real machine a simulator with adaptive PID controller of the winding machine modeling and control are presented. Diverse control parameters can be inserted manual or automatic into the simulator via LabView software interface, and the user can observe the simulation results before apply them into the real machine for finishing products, thus saving costly material and time for pre-experiments.

Keywords: LabView, winding machine, tension control, PID control, simulator.

1 Introduction
In sheet type material transport systems, maintaining the correct tension in the material of most winding machines is very important to achieve both high product quality and production output. Tension that is too small leads to softening of the material; excessive tension leads the material to over expansion, deformation and even breaking. Fluctuate tension may lead to wrinkle of material. Lower transport speed reduces the productivity, whereas higher transport speed causes unstable tension and therefore complicates the control mechanism. An optimized winding system should overcome those problems [1].

Two different methods for regulation of tension by using either tension controller with load cells, or a position controller using dancer rolls. There is no big difference in the functionality [2]. The main concern is how to get the optimized control parameters considering the coupling between velocity and tension of the material.

In the following we will concentrate on systems of large scale winding machine with material reel up to 1.2 meter in diameter and high transport linear speed up to 600 meter/min.
Main problems of winding systems are:

1. The tension of material is unstable at the start and at the moment of acceleration or deceleration of the winding machine. The tension force might exceed beyond two times of the nominal value and even break the material.

2. Quality influence by the change of production procedure: when the machine need to be stopped and restart or change the line velocity during the production, those actions will cause the tightness variation of material, and lower quality in consequence.

3. Difficulty of adjustment of control parameters: the setting of control parameters require several times of trial runs that may waste precious production time and expensive materials.

Using dancer roller to control tension for winding machine, which used for high speed and low tension material transport, has better effect, because the dancer roller acts like a buffer and damps the fluctuation of tension on material.

3 Research Target

High speed and stability are basic goals of the system design. However, as the transport speed increases, the maintenance of stable tension becomes a problem. This research attempts to build a simulator that is based on an actual machine, which use the dancer roller as position sensor. An analogous mathematic model was derived from this machine first; then, we use LabView programs in the company of control modeling to simulate the operation of winding system, and to obtain best control parameters that can be applied to real machine.

In this paper our discussion will focus on system with PID (Proportional-Integral-Differential) controller that used for fragile or low-tension materials. PID controllers are widely used in process industries, this is because the PID approach is widely understood, easy to implement, and reasonably effective for many industrial plants. But the control parameters are quite different for diverse categories such as the controls of temperature, speed, torque or position. There is no universal control scheme that work for all applications.

4 System Architecture

Figure 2a shows a simplified mechanical construction of a high-speed winding machine with 3 motors, that suitable for the processing of non-extendable materials. The control scheme based on PID controller is shown as figure 2b. The setting of tension force is by the air pressure in the cylinder, the load cell is used to measure the tension value; line velocity is controlled by transport motor; Winder and un-winder motors are servo type.

With this construction, the value of dancer position is not the tension itself but the stability of tension. If the tension is less than the setting value, then, the dancer is lifted; otherwise the dander is descended. The swing amplitude is therefore corresponded to the change of the tension.

Figure 3 shows the actual control procedure of this system, at every time interval T (Cycling Time) the PID controller calculates the driving value for un-winder or winder motor based on the differential error value of dancer position. The dancer position of the un-winder side is calculated form the difference of pull out amount of linear transporter and the drag's amount of un-winder, and then divided by two. The PID parameters are adjustable either by a pre-defined table according to the diameter of material on reel or manual.

5 Simulation Model

Base on figure 3, the simulator has following parameters, and their limit values are defined below the same as for a real machine:

- **SD**: Dancer setting Position: -1000 ~ +1000 mm
- **PD**: Present Dancer Position: -1000 ~ +1000 mm
LV: Line speed: 0~600m/min  
aT: acceleration Time: 100m / 2~30Sec  
dT: deceleration Time: 100m / 2~30Sec  
DTL: Drag Total Length  
UTL: Unwind Total Length  
UV: Unwind Velocity (rpm)  
D: Material Roll’s Diameter: 90 ~ 1200 mm  
d: Material's Thickness: 0.1mm  
Kp: PID Property factor  
Ki: PID Integral factor  
Kd: PID Derivation factor  
G: Gear ratio  
rpm: winder/un-winder rotation speed: -2000 ~ +2000rpm  
T: Cycling Time: 10ms~100ms

The calculations of each data in the control loop for un-winder:

- **Line-Velocity (LV)** is an integration of the acceleration over the elapsed time, \( dt \) is the cycling time

\[
LV_n = LV_{n-1} + a_{n-1}dt = \sum_{n=1}^{k} V'_d dt
\]

- **Drag Total Length (DTL)** is the product of the line-velocity and the elapsed time

\[
DTL_n = DTL_{n-1} + LV_{n-1}dt = \sum_{n=1}^{k} LV_n dt
\]

- **Unwind Total Length (UTL)** is the product of the unwind velocity and the elapsed time and the integration of diameter.

\[
UTL_n = UTL_{n-1} + (\pi D_{n-1}) * UV_{n-1}dt = \sum_{n=1}^{k} (\pi D_{n-1}) * UV_n dt
\]

- The total material length \( ML \) is calculated as trapezoid area, i.e. the sum of maximum diameter and minimum diameter, times the number of runs, and then divided by 2.

\[
ML = \frac{[(D_{max} + D_{min}) * [(D_{max} - D_{min})/d]]}{2}
\]

- During the simulation the speed of winder, un-winder and transporter are changed incessantly, therefore, the diameter of un-winder \( D_n \) should be derived from the difference of total material length and un-winded length:

\[
D_n = \sqrt{(ML - UTL_{n-1}) * 2d + D_{min}^2}
\]

- **Difference** \( E_n = SD - PD \)

- **Un-winder motor rotary speed** \( UV_n \) :

\[
UV_n = (K_p)*(E_n) + ([K_i/T])*(E_n) + M_{ki}E_n + (K_d)*[(E_n-E_{n-1})]
\]

Due to the rating speed of the selected servomotor is 2000rpm, therefore we limit the motor speed \( UV_n \) to:

\[
\text{if } UV_n > 2000 \text{ then } UV_n = 2000
\]

In case of material breaking during the operation, the motor will run reversal at a very high speed; to avoid this situation the reverse speed is limited under 100rpm (this setting can be altered by case):

\[
\text{if } UV_n < -100 \text{ then } UV_n = -100
\]

The values for winder are calculated similarly as above.

Note that the system is nonlinear. Also, the PID control parameters are not constant. They will be influenced by the following factors:

- Tension value setting
- Acceleration/Deceleration time
- Ratio of gear motor
- Cycling time setting
- Maximum line-velocity
- Material thickness and the changes of material diameters
- Change of production's procedure

Therefore, using an adjustable parametric PID table according to the changes of environment might balance this problem.

6 Simulator Implementation

Figure 4 shows the operator's control panel based on LabView software. On the panel, circular meters
Fig. 4. Main operator's control panel indicate the line-velocity, diameter of material on winder and un-winder (mm), motor speed (rpm) and dancer position (mm).

The PID parameters can be entered manually by the user (operator) or from a pre-defined table for auto-adjustment. According to the Ziegler Nichols tuning method[3], the PID parameters at maximum diameter were obtained first:

\[
K_p = 0.12 \quad K_i = 0.007 \quad K_d = 28
\]

Then change the diameter with this method sequentially; the rest PID parameters were built-up as table 1. Manual input of parameters is used for trial runs in the simulator to find the best values and build-up a PID control table (Tab. 1 for winder), the table for un-winder can be build-up similarly. The selection of auto-adjust mode for simulation is used to verify this control table and gain results of the total performance in this system.

Fig. 5. Calculation of current PID parameters

<table>
<thead>
<tr>
<th>Diam. (mm)</th>
<th>Kp</th>
<th>Ki</th>
<th>Kd</th>
</tr>
</thead>
<tbody>
<tr>
<td>60-10</td>
<td>0.9</td>
<td>0.06</td>
<td>20</td>
</tr>
<tr>
<td>110-150</td>
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<tr>
<td>360-500</td>
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<tr>
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<td>560-600</td>
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<tr>
<td>610-650</td>
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<td>20</td>
</tr>
<tr>
<td>660-700</td>
<td>0.12</td>
<td>0.01</td>
<td>20</td>
</tr>
</tbody>
</table>

Fig. 6. Un-winder PID controller

Fig. 7. Diameter and dancer position calculation

Fig. 8. Transporter speed and pullout length calculation
Figure 8 shows calculations of the lineal velocity and the pullout length, lineal velocity is calculated by \( V = \Sigma a^*\Delta t \), where \( a \) = acceleration and \( \Delta t \) = cycling time; the pullout length of the transporter is then calculated by 

\[ \text{Length} = \Sigma V_n^*\Delta t. \]

Adjustable ranges of each parameter in the simulator and their default value in parentheses are listed below:

- Line-Velocity: 0 ~ 600 m/min, (600)
- Acceleration time 0 to 100m: 2 ~ 30 Sec, (5)
- Dancer setting position: -1000 ~ 1000 mm, (0)
- Initial un-winder diameter: 90 ~ 1200 mm, (1200)
- Initial winder diameter: 90 ~ 1200 mm, (90)
- Cycling Time: 1 ~ 1000 ms, (100)
- Material Thickness: 0.01 ~ 10 mm, (0.1)
- Ratio of Gear Reducer (G): 1 ~ 10, (2)
- The motor's angular speed after gear reducer must larger or equal maximum linear speed at minimum diameter of material.

\[(2000 \text{rpm/G}) \pi \text{min. diameter} \geq \text{Max. Line Speed}\]

- Min. motor rotary speed: 0 ~ -100rpm, (–100)
- -100 indicates 100rpm reverse
- \( K_p\_uw \): Kp of un-winder (0.12)
- \( K_i\_uw \): Ki of un-winder (0.007)
- \( K_d\_uw \): Kd of un-winder (28)
- \( K_p\_w \): Kp of winder (0.9)
- \( K_i\_w \): Ki of winder (0.06)
- \( K_d\_w \): Kd of winder (28)

7 Simulation Results

Figure 9b shows a portion of simulation results of the winding machine, the dark blue curve represents the diameter of un-winder; the bold red curve represents the dancer position: the green curve represents the motor speed and others as indicated in figure 9a. Unit of horizontal axis is the numbers of cycle time; unit of vertical axis refers to the unit of circular meters. All simulation results are plotted in curves and recorded in a database for further detail analysis (Tab. 2). This table contains line velocity, dancer position, reel diameter and PID parameters at every time interval.

Figure 10 shows the influence of PID parameter settings to the winding machine. By employing the auto adjustable PID table, the fluctuation of tension will be under control.

8 Conclusion and future works

The swing amplitude of dancer influences the

![Fig. 9a.](image)

![Fig. 9b. Waveform of a Simulation](image)

![Fig. 10. Comparison of simulation results with fixed PID parameters and adjustable PID parameters](image)

<table>
<thead>
<tr>
<th>Tab. 2. Simulation Record</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Cycle Count</th>
<th>Line Speed (m/min)</th>
<th>Dancer Position (mm)</th>
<th>Motor Speed (rpm)</th>
<th>Winder Dia (mm)</th>
<th>Kp</th>
<th>Ki</th>
<th>Kd</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>1000</td>
<td>7.889</td>
<td>254.988</td>
<td>1714.707</td>
<td>1.26</td>
<td>0.9</td>
<td>0.06</td>
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<td>254.988</td>
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<td>0.06</td>
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<tr>
<td>1800</td>
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<td>0.06</td>
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<tr>
<td>2000</td>
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<td>1714.707</td>
<td>1.26</td>
<td>0.9</td>
<td>0.06</td>
</tr>
</tbody>
</table>

dimension, construction and precision of the machine. The swing of the dancer corresponds the variation of tension. With the smaller value, the length of dancer arm can be reduced. Furthermore, the stability of mechanical structure can also be enhanced. The time to reach stable state and numbers of swings are both reduced, which improves also the productions quality.

From the observations, we found similar results between the simulated virtual machine and a real one. However a
numerical comparison is not easy to carry out, due to the difficulty of direct measurement from the machine that in use. The correctness and accuracy of this simulator needs to be verified in the future.

In general, using this simulator, the optimal PID parameters can be obtained as table 1, which helps manufactures in the system design and the users in the operation for enhancement of the machine performance and production.

References


