Study on variable PI parameters of looper system based on Fuzzy control

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Abstract

To improve the stability and response speed of looper tension, the influence of looper height and looper vertical acceleration on the tension stability was studied, apply fuzzy variant PI control method. The method optimization of PI controller parameters base on below 3 control loops: speed loop,torque loop and speed loop saturation torque loop limited, solves the problem of looper height and vertical acceleration decoupling. By this way tension in different conditions can meet the production requirements of the stable state. The result show, variant PI parameter fuzzy control on looper tension control, can significantly improve the tension of the loop system stability, thereby improve the strip production line production rhythm, to meet product quality requirements.

Keywords

Looper, tension, fuzzy control, PID, variant PI parameter.

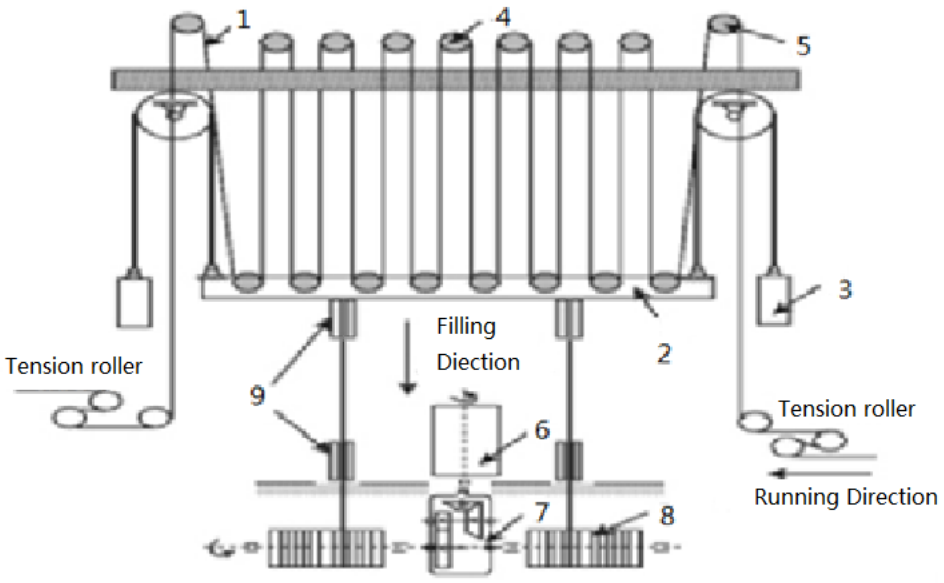
1. Introduction

Looper is the key equipment in modern pickling line, continuous annealing and galvanizing process line [1]. In order to guarantee continuous production process stability, looper in loading and buffer production aera has played a pivotal role [2]. In order to avoid product migration and pleating, so need strip in looper always maintain constant tension[3]. Looper height and tension is the two input two output compound system. For easy control, normally we see it as two independent single input single output control system, design the PI controller separately. The coupling disturbance of each subsystem is handled independently, and the real-time dynamic tension compensation [4]. But this method ignores coupling between looper tension and the looper height and looper vertical speed change rate (acceleration). Especially in filling and empting looper process. In this process period, the strip speed rate change significiant, so the system is less robust. Shioya[5]. designed a kind of interference compensation without interactive control method, the method can reduce the impact of low frequency disturbances, thereby suppressing noise and modeling errors. However, the proposed method improves the robustness of the system by sacrificing the performance of disturbance rejection. To solve the looper tension coupling effect due to Looper height and vertical acceleration, The paper presents variable PI parameters of looper system based on Fuzzy control method.

2. The composition analysis of the driver system

The data of the paper comes from data base on South - South aluminum plant 1800mm air - cushion heat treatment production line entrance looper. The entrance looper consists of vertical moving trolley, winch, counterweight, roller table and tower steel frame. In filling and empting cycle, the winch will pull the trolley up and down movement, while the encoder real-time collection of the current position of the trolley. 2 sets of centering devices are provided for the whole looper, ensure that aluminum strip will not run deviation during continuous operation, as show in Fig.1.

Siemens PCS7 was applied to control system, The driver system used Siemens S120 vector control inverter, network system adopts Profibus-DP.



1—Driver; 2—trolley; 3—counterweight; 4—looper fixed roller set; 5—centering roller; 6—Winch motor; 7—gear box; 8—hoist; 9—pulley group

Fig.1 Looper equipment

As is clear from FIG. 1 The looper motor draw single wire rope, The formula is as bollow:

$$F = \frac{16 \times T + WS}{2} \quad (1)$$

WS: Aluminum weight, T: Tension of Aluminum strip

Trolley is close to the counterweight weight, they can offset each other, so we can ignore the weight difference between them. That is, M electromagnetic =M load. In the engineering practice, the gearbox chooses the small reduction ratio as far as possible, so as to reduce the influence of flywheel torque CD2 in the process of starting and braking.

$$4TD/iCM\phi = ISet <= (8T+WS)\ D/2\ iCM\phi \quad (2)$$

D: Roll diameter, i: gear box reducer ratio, CM: Electromagnetic torque constant., ϕ Magnetic flux.

During production process inculde filling and empting process, the aluminum strip in the looper always maintains the constant tension T. Because in filling and empting process, the motor runs in opposite directions and torque keep constant direction, will lead to the motor in electric and power generation two opposite states. Especially in the power generation state, mechanical energy will feedback to grid. So choose vector inverter, the braking unit and the braking resistor power parts of the inverter should meet the energy consumption requirements, or choose to support the four-quadrant energy feedback vector inverter.

3. Looper parameters calculating

Absolute encoder on the roller to collect looper height data; entrance speed (v_entry) and exit speed (v_process) of looper according to speed of S rollers that is installed entrance and exit of looper; The tension of strip in the looper measure by tensiometer that installed on tension roller. Except directly measure data, the decoupling algorithm needs to derive some process parameters from these basic data.

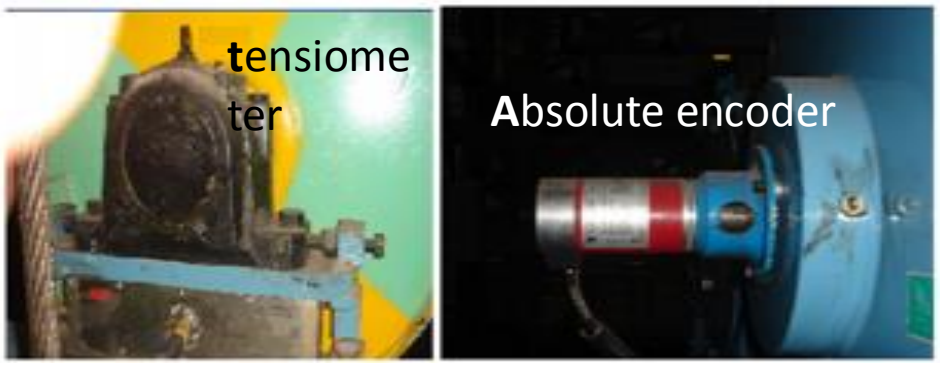


Fig.2 Looper Sensors

According to the system configuration, the vertical speed(v_winch) and the line speed of the looper(v_roll) can be deduced:

$$v\_winch = \frac{v\_entry - v\_porcess}{strand\_count} \tag{3}$$

$$v\_roll = \frac{v\_entry - v\_porcess}{strand\_count} \times (roll\_count - roll\_number) \tag{4}$$

$$a\_roll = \frac{a\_entry - a\_porcess}{strand\_count} \tag{5}$$

The looper acceleration program is written in the interrupt program of PCS7 system OB35 (100ms).

$$a\_enrty = \frac{dv}{dt} = \frac{v\_entry\_current - v\_entry\_last}{0.1} \tag{6}$$

V_winch:looper vertical speed v_enrty:looper entrance speed v_process:looper exit speed V_roll:looper line speed a_roll:looper vertical acceleration a_entry:looper entrance acceleration a_process:looper exti acceleration strand_count: strand of looper

4. Looper process description

The function of the looper is to ensure the continuity of the production process, In actual production, the height of the looper is limited by the environment of the workshop, The speed of production process will be deliberately reduced in the process of setting(Fig.3). The working state of the looper is divided into 3 states:

Full state: normally, the looper trolley stop in a full position（90% capacity of looper）, looper full position can be set in HMI, In this state looper entrance speed=exit speed=process speed

Empty state: When the strips on the unwind machine remain the last few laps, entrance section S roll slow down. To maintain the speed of the process section stabile, the trolley need running up and empty looper. Normally empty position(can be set in HMI) lower than 15% looper capacity. lower than this level, The trolley will be stoped, then the process equipment also stops accordingly, This kind of stop state is considered a fault state, should requiring the operator to deal with it.

Fill state: After the end of the unwind machine roll change, The entrance S roll is first accelerated to high speed, due to process segment should keep steady speed, trolley move down, when the trolley move to full position, entrance S roll slow down to process speed, ensure looper keep in full position.

So, we should control trolley vertical position, the trolley runs up and down is controled by the speed of the looper entrance and the exit speed difference. Beacuse the exit velocity of the looper (v_ process), remains unchanged in the production process. So, ultimately, by adjusting the entrance speed of the looper to ensure the location of the trolley, see formula (7). When trolley works in full position. the system reached balance state, that is, entrance speed=exit speed.

$$v\_entry = v\_process \times (\triangle h * k + 1) \quad (7)$$

△h: Deviation between setting height and actual value of looper, k:Coefficient of proportionality

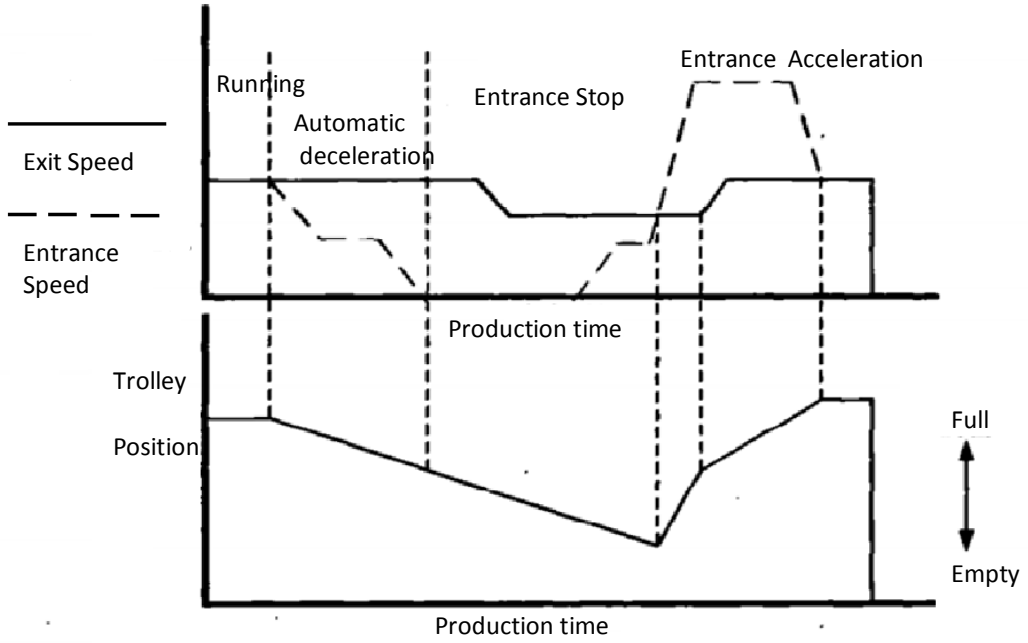


Fig.3 Looper working status

5. Variable PID fuzzy control tension algorithm

In continuous annealing process, the tension of the product directly affects the product quality parameters, in order to produce high-quality annealed products, the looper tension must be precisely controlled. Looper tension mainly affects the quality of products in the following 4 aspects:

(1) Maintain a certain constant tension, prevent strip deviation, reduce CPC (Centering device) too frequent movement.

(2) The entrance looper provides constant tension for the process section to ensure the product profile and quality.

(3) The exit looper provides the necessary tension for the coiler to ensure the quality of the product windup.

(4) Looper static tension control, reduce equipment vibration at startup.

In the paper, the fuzzy control method with variable PID parameters is used to realize the tension control. The controller consists of 2 parts. The first part is PI closed loop control; the second part is the fuzzy optimization of PI parameters.

For the first part of the PI closed-loop control, PV tension measurements collected from tensiometer. According to the characteristics of the motor and the mechanical characteristics of different looper, the PI control loop can be established for 3 different physical quantities. If you use the first two methods mentioned as below, you should to consider safety factors such as belt breakage.

5.1 Closed loop PI regulation based on speed loop

A closed loop is formed by adjusting the tension feedback value (PV) and the tension setting value(SP) to adjust the speed of the winch motor, In filling and empting process, the winch motor are in the electric and power generation states respectively, motor works in 1st and 4th quadrant. When working in the fourth quadrant, the current will be feed back to the grid.

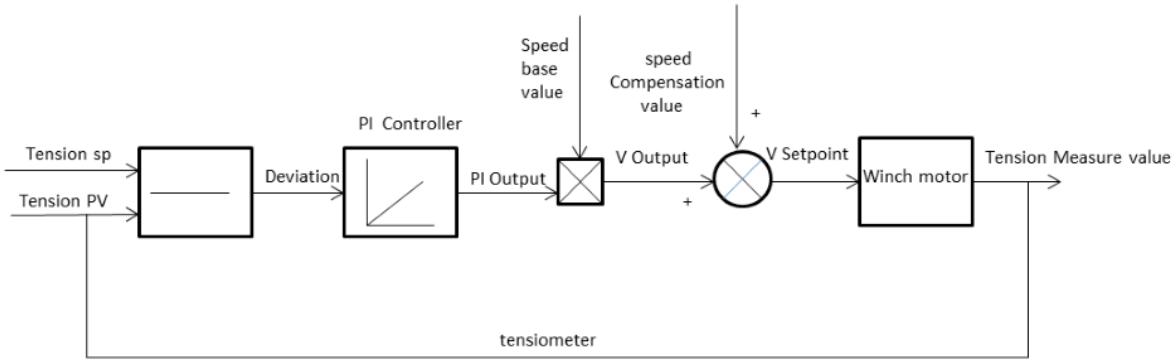


Fig.4 Speed loop PI control

5.2 Closed loop PI regulation method based on torque loop

The torque calculation value of the looper is calculated by the tension setting value of each strip in the looper. No matter whether the looper is in the state of filling or empting, the ultimate objective of the looper is to ensure the strip that in the looper maintains a constant tension. Due to the tension direction of the strip is constant and the direction of the motor changes, which means that the motor switches between the first quadrant and the fourth quadrant.

$$\text{Torque calculte} = \frac{\text{Tension setting value of each strip} \times r}{i} \times n \tag{8}$$

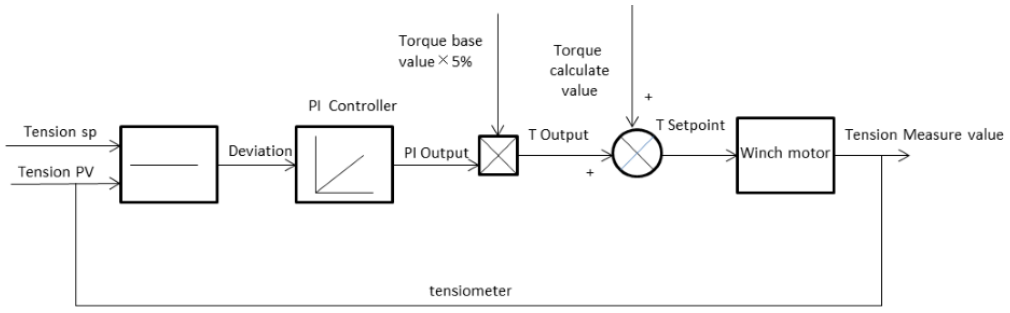


Fig.5 Torque loop PI control

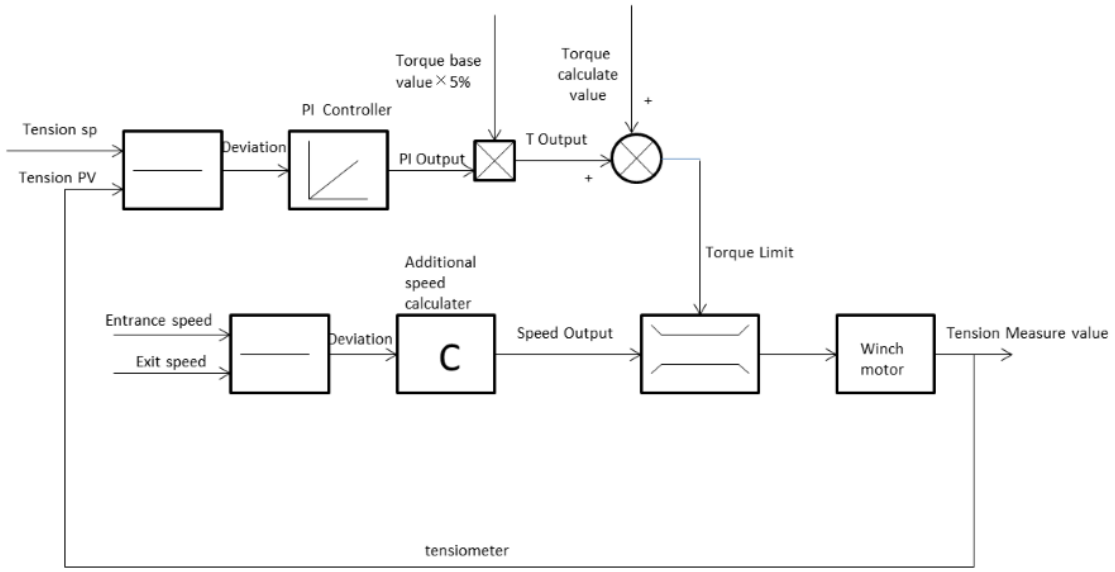


Fig.6 Speed loop saturation, torque limited

5.3 Torque limiting PI regulation mode of speed loop saturation

Similar to the torque control method, the torque limiting value is the equale to the torque calculation value. The difference is that the torque loop is indirectly controlled by the velocity loop saturation. Speed loop saturation leads to torque is limited, by this methed realize the function of torque control

Because of the coupling relationship between looper tension and looper height and vertical acceleration of looper, If only use one set of PI parameters to control the looper tension according to the 3 methods that described above, looper tension will fluctuate greatly in different process statge. So it is necessary to decouple the looper tension.

The second part of the algorithm is to use fuzzy control method to select one of sets PI parameters from several group parameters. The core of algorithm is to find out the relationship between looper height, looper vertical acceleration and tension. So then optimize the PI parameter.

Because the tension of looper is coupled with the height of looper and the vertical acceleration of looper, so it is necessary to set up 2 sets of different fuzzy sets. The final fuzzy control table is obtained by two fuzzy sets integrated. fuzzy control system precision is related to the number of input and output variables. The more fuzzy interval was divided, the higher control accuracy will be get, but the control rules are correspondingly complicated; On the contrary, the less fuzzy interval was divided, the control rules are simplified, but the control accuracy can not be guaranteed. So, overall consideration,NB,NM,NS,ZO,PS,PM,PB 7 fuzzy interval is divided.

System input: Looper height h, vertical acceleration a;

System Output PI parameter:ΔKP;

$$\begin{matrix} h \\ \begin{pmatrix} NB \\ NM \\ NS \\ ZO \\ PS \\ PM \\ PB \end{pmatrix} \end{matrix} \rightarrow \begin{matrix} \Delta KP \\ \begin{pmatrix} 0.1 \\ 0.06 \\ 0.05 \\ 0.06 \\ 0.05 \\ 0.06 \\ 0.09 \end{pmatrix} \end{matrix} \qquad \begin{matrix} a \\ \begin{pmatrix} NB \\ NM \\ NS \\ ZO \\ PS \\ PM \\ PB \end{pmatrix} \end{matrix} \rightarrow \begin{matrix} \Delta KP \\ \begin{pmatrix} 0.18 \\ 0.07 \\ 0.05 \\ 0.06 \\ 0.09 \\ 0.11 \\ 0.16 \end{pmatrix} \end{matrix}$$

Input h and a set different weights for the influence of output ΔKp, Assuming h on the ΔKp weight is 0.4, a of the weight is 0.6. Weighted operations are performed on two fuzzy sets, Form a new fuzzy control table, As shown in Table 1.

Table1 ΔKp Fuzzy control array

	NB	NM	NS	ZO	PS	PM	PB
NB	0.148	0.082	0.07	0.076	0.094	0.106	0.136
NM	0.132	0.066	0.054	0.06	0.078	0.09	0.12
NS	0.128	0.062	0.05	0.056	0.074	0.086	0.116
ZO	0.132	0.066	0.054	0.06	0.078	0.09	0.12
PS	0.128	0.062	0.05	0.056	0.074	0.086	0.116
PM	0.132	0.066	0.054	0.06	0.078	0.09	0.12
PB	0.144	0.078	0.066	0.072	0.09	0.012	0.132

The purpose of defuzzification is clarity, the reason for defuzzification is to convert the fuzzy value into the exact value. In the process, the method of maximum membership degree is adopted, Essentially, the maximum value of the membership function is taken as the final exact value.

$$\begin{cases} Kp = Kp_0 + \triangle Kp \\ Ki = Ki_0 + \triangle Ki \end{cases} \tag{9}$$

In the formula, Kp0 and Ki0 are the initial values of the PID parameter, according to the vertical acceleration(a) and height (h) of looper calculate the Kp value and Ki value by fuzzy control table. Finally, the additional value and the initial value are added to get the final Kp and KI values that applied to the actual PID operation. Fuzzy control variable PID parameter control method makes looper tension in different height and variable speed, the tension of the strip in the looper can be keep within a stable fluctuation range.

Fig7 is PID control effect for fixed PI parameters, by Figure 7, it can be seen that the PID algorithm with fixed parameters, when the looper height is different, the tension fluctuation deviation is very large. Fig. 8 is a variable parameter PI fuzzy control effect diagram. Compared with Figure 7, the tension stability is improved significantly.

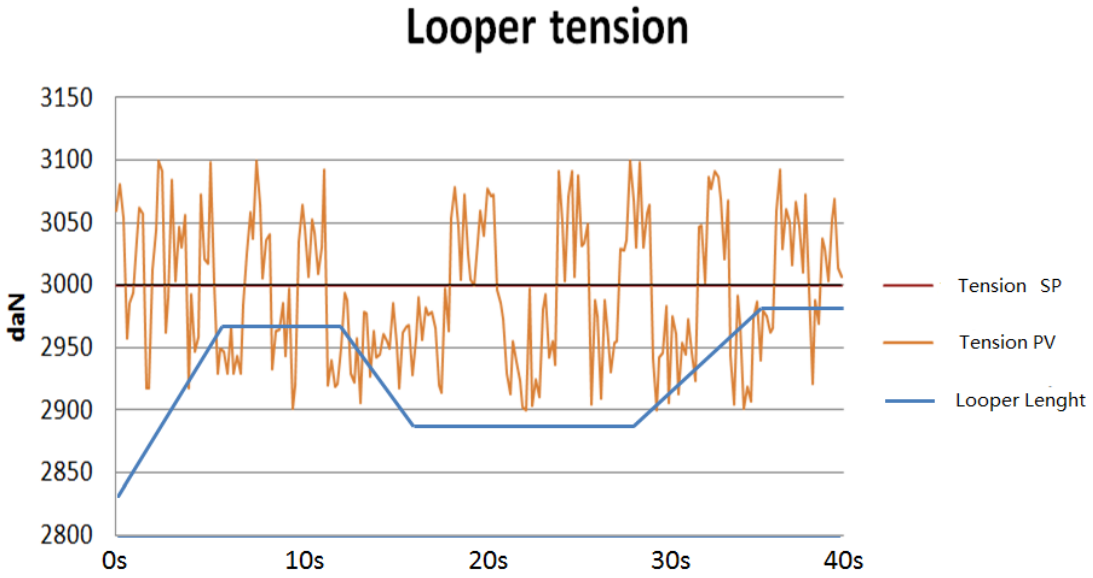


Fig.7 without fuzz control, lopper tension and height record

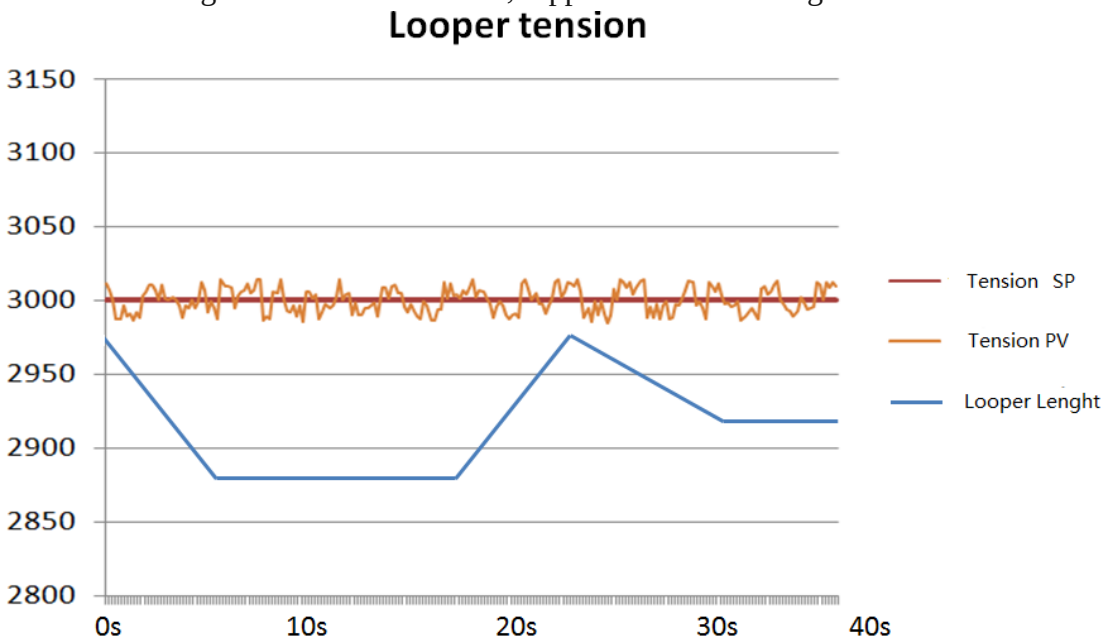


Fig.8 with fuzz control, lopper tension and height record

6. Conclusion

The variable PI parameter fuzzy control method is applied to adjust the looper tension in the South aluminum 2800mm air cushion heat treatment production line project. The application proves that the looper is in the process of filling and empting (i.e., varying height and speed), Compared with the control mode of fixed PI parameters, It can obviously improve the stability and response speed of

looper system tension under different working conditions, So as to improve the production rhythm of strip production line and meet the product quality requirements.

References

[1] Qian Xiaolong, He Mingsheng. MITSUBISHI PLC control system of continuous annealing line in Benxi Steel Pohang cold rolling mill [M],Shenyang: Northeastern University press, 2006,17-25
[2] Wang Shuichu. Decoupling control system. Sichuan Science and Technology Press
[3] Li Xu. Decoupling height and tension control system of looper by feature locus method. Information and control, 2005, 6
[4] Yang Jingming. 1450mm Looper tension control system of tandem cold mill. Electrical drive, 2008, 12
[5] Shioya M, Yoshitani N, Ueyama T. Non interacting control with disturbance compensation and its application to tension looper control for hot strip mill [C]// Proceedings of the 1995 IECON.[S.1.]: IECON 1995;229-234.
[6] Oberson Luke B, Poggi Mark A, Kowalik Janus Z, etal. Correlation of morphlogoy and device performance in igorganic — organic TI O2 — Polythiophene bybrid solid — state solor cell[J]. Coordination Chemistry Reviews, 2004,248(14): 1491-1944
[7] Hao Longgang. Application of Rockwell PLC in the looper control system of cold rolling mill[J]Electrical technology, 2008, (1) : 18 - 19.
[8] An Lianxiang, Li Dong, Jing Zheng. Design of looper tension control system for annealing line[J]. Journal of iron and Steel Research,2010, (10) : 6 − 7.
[9] Wen-Shyong Yu. Adaptive fuzzy PID control for nonlinear system with H Tracking performance[J].2006 IEEE international conference on Fuzzy system,2006;1010-1015
[10] Mizumoto M. Realization of PID controls by Fuzzy control method[J], Fuzzy set and system, 1995,1(70);171-182