Anti-interference Strategy of 20-Hi Cold Mill Automatic Gauge Control

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Abstract: Automatic gauge control (AGC in the article) is the key technology of product thickness accuracy and flatness quality in modern cold rolling mill. Most traditional AGC control algorithms need stable external system conditions and hard to stabilize under complex interference that meets coverage requirements. This paper presents a new anti-interference strategy for AGC control of 20-Hi cold reversing mill. The proposed algorithm introduces a united dynamic weights algorithm of feed forward-mass flow to avoid the complex interference problem in AGC control, the relevant control strategy is provided to eliminate the adverse effects. At the same time, the D-value between feed forward-mass flow pre-computation and thickness measurement deviation is dynamic compared, the final gap position regulation is calculated by developing a set of united dynamic weights between feed forward control and mass flow control. Finally, the output of controllers is sent to actuator though a constant rate smoothing. The proposed strategy is compared with conventional AGC control on Experimental platform and project application, the results show that the proposed strategy is more stable than comparison method and majority of system uncertainty produced by mentioned interference is significantly eliminated.

Keywords: 20-Hi Cold Mill, Complex Interference, AGC Control, United Dynamic Weights, Anti-interference

1 Introduction

Thickness accuracy is the most important product quality target of cold rolling strip, and AGC control is the key technologies to determine thickness accuracy in modern cold mills. AGC control in rolling process is characterized by multi variable, strong coupling, deep nonlinearity and extreme fast, control cycle is required to be accomplished in milliseconds. As one of the most complex industrial control processes, AGC control of modern rolling mill has been guiding the trend of automatic control technology development.

The existing AGC control normally develops in basic automation system(BA). Currently, most traditional AGC control adopt the direct superposition method of algorithm of feed forward AGC, feedback AGC and mass flow AGC are composite applied. However, for complex interference, traditional AGC control cannot stabilize expectedly and need additional enhancement strategy under coupling relationship, so it is difficult to achieve ideal target rely on direct superposition method. This paper studies the anti interference strategy of 20-Hi cold reversing mill.

Solving the problem of complex interference using combinatorial algorithm has always been a research hotspot. Hitachi Japan developed the hybrid AGC, uses the combination of AGC control and tension control for automatic mode selection to overcome the change of speed and strip thickness[1].

Aimed at shortcomings of stable coordination of feed forward AGC and feedback AGC, Dong introduced Smith prediction control to improve the coordination accuracy of feed forward control and feedback control for the anti-interference function[2-3]. Using additional algorithm to solve the system interference problems, the above studies mostly focus on the improvement of the fitness function or on the improvement of the algorithm itself, ignored the relationship between the algorithm and the problem to be solved. Therefore, this paper presents an improved anti interference strategy, a united dynamic weights algorithm which can avoid the complex interference problem in rolling process, and balance the relationship between three kinds of AGC sub control. It can be applied in improving the thickness quality index of cold rolling products.

2 Main Instrument and Components of 20-Hi Mill

High magnetic induction oriented silicon steel and high efficient electrical motor steel are the main products of cold 20-Hi mill. Steel coil after hot rolling or pickling normalizing get thickness reduction by 4 to 5 reciprocating rolling, while the strip shape, surface roughness and steel physical properties will greatly improved after the process, become high-quality cold rolling products. The thickness range of rolling products is 0.2mm~0.5mm, the range of raw material coil is 2.0~2.7mm, and the thickness requirement of final product must not exceed ±5μm. The automatic gauge control system includes 3 controller including feed forward(FF), feedback(FB) and mass flow(MFC), plus a rolling efficiency compensation during deceleration or acceleration. 20-Hi cold mill use smaller work roll than other major manufacturer's, its HGC main rolling force comes from one medium diameter hydraulic cylinder on top of the one-piece housing[3].

Instrument configuration of the 20-Hi mill are shown in Fig.1, two sets of ray thickness gauge from IMS, laser velocimeters from Beta, tensionmeters from ABB, are equipped in the entry and exit side of mill housing. A high accuracy position sensor from MTS is equipped in the AGC cylinder for roll gap position measurement, which accuracy is less than or equal to 0.1μm. The oil inlet of AGC cylinder equipped with high response rate pressure sensors for calculation of rolling force. Behind the main drive motor, high resolution encoders are equipped for line speed measurement, their pulse signals are sending to the FM458 through a signal distributor.

3 Complex Interference in AGC Control

Generally, the product thickness will change (decrease or increase) while the raw strip change (decrease or increase), that is the essential of the product thickness deviation[4], the product goes worse when raw strip unqualified. Because of the quick temperature drop and the deformation resistance growth in hot milling process, is hard to stabilize the thickness quality of hot milling coil's head and tail. The raw strip source line in previous process is overused and long term short of fine maintenance, plus the improper temperature control, bringing disadvantages such as thickness oversize and sharp fluctuations to our 1300mm 20-Hi mill. As shown in Fig.2, the mentioned disadvantages along with center buckle and edge buckle form a complex interference of raw strip.

The mill emulsion system is designed for roll and strip cooling during rolling, emulsion cycling and recycling, roll lubricating, roll and strip cleaning, reflectivity enhancing of the strip surface, etc.. The saponification value and the concentration value of emulsion system are critical to a steady rolling process. The emulsion system of this particular 1300mm 20-Hi mill has undulated cycle period, which led to a nonnegligible change in the saponification or the concentration value. The uncertainty of emulsion system could lead to a quality defect of final product even cause a strip break.

In summary, the interference of raw strip and emulsion system constitute the complex interference in this particular 20-Hi reversing mill.

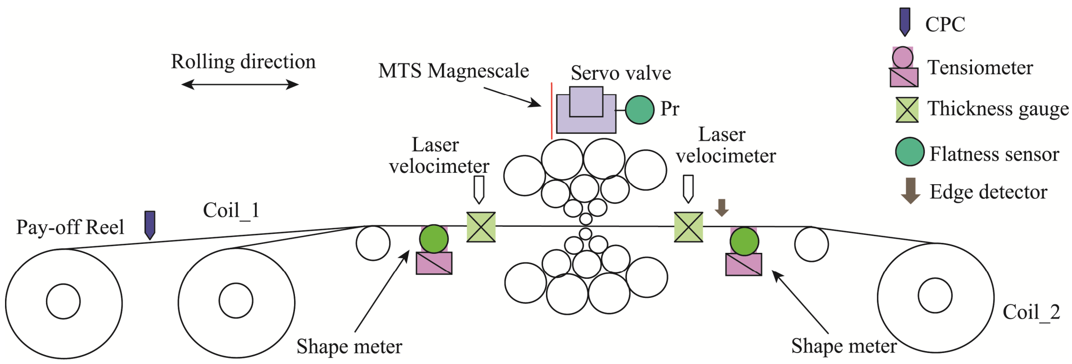

Fig.1 Main Components and Instrument of 20-Hi Cold Mill

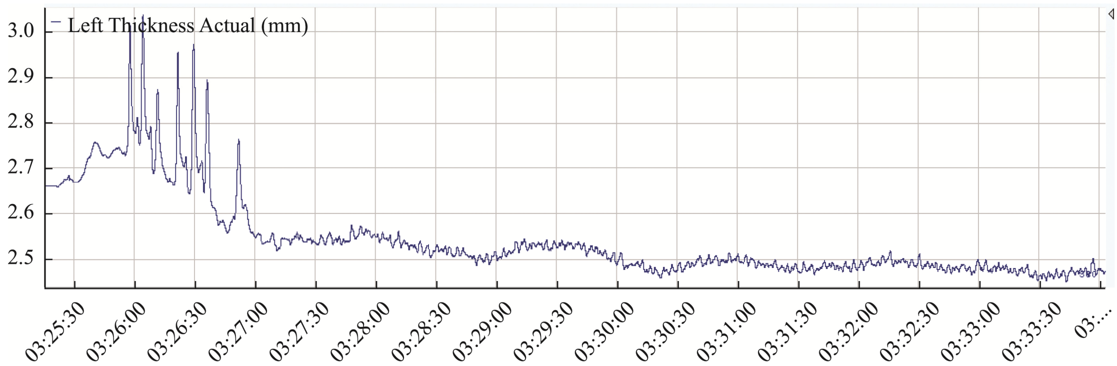

Fig.2 Raw Strip Thickness Measurement Curve of 20-Hi Cold Mill

4 Automatic Gauge Control Algorithm

Among the three AGC methods of feed forward, mass flow and feed forward, Mass flow AGC is a kind of highly sensitive control, which is the main method to reduce the thickness deviation when the line at high speed. Feed forward AGC is a kind of open loop control be applied for reduce the thickness deviation of mill inlet, because its convergence ability is minor, its regulation takes a minor proportion in the three AGC modes, so it needs to combined use with other 2 control methods. Feedback AGC is a slightly lag mode control, good at the situation of low speed or continuous rolling process cumulative deviation[5], such as long-term change caused by the rolling thermal expansion, roll consume, etc.

4.1 Mass Flow Control

According to the theory that 'same volume metal flow in and out mill during the same time', mass flow AGC represent the relationship between steel thickness and roll gap. Accurate measurement of strip speed is a premise for process computation of metal volume flow. This 1300mm mill equipped two laser velocimeter at inlet and outlet of the mill housing, so the rolled strip thickness of 20-Hi mill can be calculated according to the mass flow theory [6, 7].

$$t_{2,MF} = \frac{V_{En}}{V_{Ex}} \times T_{1,Thg} \qquad (1)$$

In Eq.(1), V_{En} indicates the speed measurement by entry laser velocimeter, V_{Ex} indicates the speed measurement by exit laser velocimeter, $T_{1,Tng}$ indicates the thickness measurement by entry gauge.

The purpose of MFC calculation is improve the accuracy of the outlet thickness of the mill, so a thickness compensation variable Δh_{com} the is proposed. As shown in Fig.3, the D-value between the exit thickness gauge and the thickness precalculation. The key point is the time-lag between two thickness gauge measurement and AGC execution, once a measurement signal of the entry gauge is received, an outlet strip thickness can be precalculated according to the Eq.(1). Due to the lag, the precalculation must be synchronous transferred from the entry gauge to the roll gap by a program register LPM1 , then be synchronous transferred from roll gap to the exit thickness gauge by a program register LPM2

$$\Delta t_{com} = T_{2,Thg} - t_{2,MF[LPM3(LPM2)]} \tag{2}$$

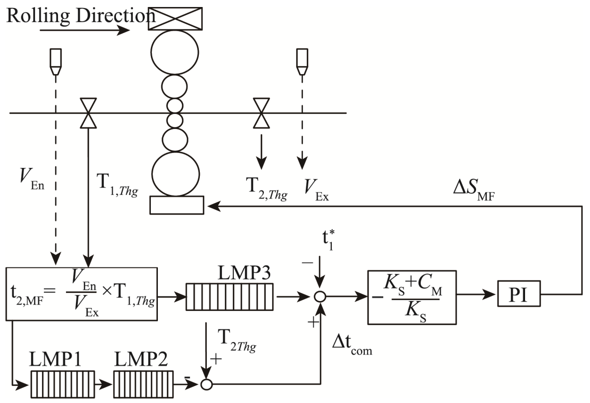

Fig.3 Mass Flow AGC Algorithm of 20-Hi Cold Mill

In Eq.(2), $T_{2,Tng}$ indicates the exit thickness gauge measurement, $t_{2,MF[LPM3(LPM2)]}$ indicates the pre-calculation be synchronous transferred from entry gauge to the exit gauge. According to this variable, the thickness deviation $\Delta t_{2,MF}$ can be deduced. In the calculation, $\Delta t_{2,MF}$ is synchronous transferred from roll gap position to the exit gauge, and the final thickness deviation is:

$$\Delta t_{2,MF} = t_{2,MF(TPM2)} - t_1^* + \Delta t_{com} \tag{3}$$

In Eq.(3), $t_{2,MF(TPM2)}$ indicates the calculation synchronous transferred from entry gauge to the roll gap position, t_1^* indicates exit thickness set value.

Finally, a PID controller applying to $\Delta t_{2,MF}$, meanwhile mill stiffness coefficients and material modulus [8-10] is employed, the regulation of mass flow control is:

$$\Delta S_{MF} = \mathrm{PID}\left(\frac{K_s + C_M}{K_s} \times \Delta t_{2,MF}\right) \tag{4}$$

In Eq.(4), C_M indicates the material modulus, K_S indicates the stiffness coefficients, PID( ) indicates the PID controller. Discrete type PID control algorithm as:

$$Q_n = Q_{n-1} + \frac{T_S}{T_N} \times X_n + K_p X_n \tag{5}$$

Q_n and Q_{n-1} indicates output of PID controller in n and n-1 timing. X_n indicates output of PID controller in n timing, T_S indicates the sampling cycle setting of SIEMENS module FM458, T_N is integral period, K_P is proportional parameter setting.

4.2 Feed Forward Control

Whether feedback automatic thickness control system using a thickness gauge or a “thickness calculation”, the transfer lag or the transition process lag in control is a limitation for improvement of control accuracy. Especially when the incoming raw material thickness significant unstable, it will affect the accuracy of the actual rolled strip thickness, so Feed forward gauge control system is widely used in modern cold rolling. The feed forward AGC control the thickness according to the thickness deviation ΔH in advance determines before the rolling process, not the deviation value of the actual rolling thickness measurement, adjust the screw down actuator within a predetermined time to ensure that the required rolling thickness h is obtained, As shown in Fig.4. Due to it sends signals to automatic thickness control in advance, it also called pre control AGC.

The principle of feed forward AGC is to measure the inlet strip thickness H_i with a thickness gauge before it enters the mill housing, compared with the set thickness value H_0, when there is thickness deviation ΔH, the possible rolled thickness deviation Δh can be estimated in advance, so the amount of roll gap regulation ΔS_{Foward} to eliminate this deviation Δh can be determined. Then, calculate the time required for the inspection point moving enters the mill plus the gap action time for ΔS , so that the thickness control point is exactly the inspection ΔH point.

According to the stiffness test curve P-h diagram (test before commissioning), The relationship between

ΔH, Δh and ΔS_{Foward} can be determined from the stiffness theory, seen that:

$$\Delta h = (\frac{C_M}{K_S + C_M})\Delta H \quad (6)$$

it follows that

$$\Delta S_{\text{Foward}} = \frac{K_S + C_M}{K_S}\Delta h = (\frac{K_m + M}{K_m})(\frac{M}{K_m + M})\Delta H \quad (7)$$

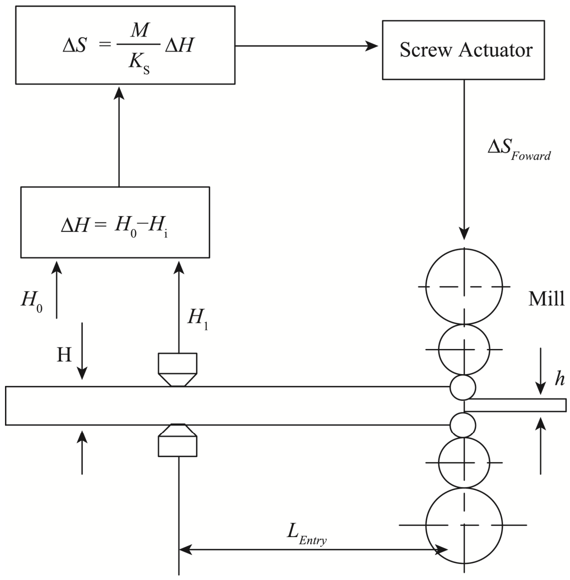

Fig.4 Feedforwad AGC Algorithm of 20-Hi Cold Mill

The Eq.(6) and Eq.(7) shows that the larger K_S and the smaller C_M, the smaller movement ΔS_{Foward} required for the hydraulic system to eliminate the same incoming thickness deviation ΔH . Therefore, the mill with larger stiffness coefficient is conducive to eliminating the incoming raw thickness deviation. Moreover, It can be said the mill has a certain automatic correction ability for the thickness deviation.

Feed forward AGC is generally combined with and other thickness control methods and its control effect can only be evaluated together with other control methods.

5 Anti-interference Strategy

The total value of gap regulation ΔS_{Foward} from feed forward control and the gap regulation ΔS_{MF} from mass flow control are directly output to the position controller through a limiter[11,12]. Then output of AGC controller is sending to the actuator (for example Servo valve or hydraulic cylinder) so that the amount of this two units is

$$\Delta S_{\text{Sum}} = w_1 \times \Delta S_{\text{Foward}} + w_2 \times \Delta S_{\text{MF}} \quad (8)$$

In traditional AGC theory, both w_1 and w_2 equal to 1.0, once the complex interference appears during the rolling process, the regulation ΔS_{Foward} and ΔS_{MF} become mutually exclusive occasionally (one is positive, another is negative) [13], it will bring instability to the production, even product quality problem, so traditional AGC theory under complex interference must be improved.

According to Eq.(3), $\Delta t_{2,\text{MF}}$ can be the expected thickness deviation of regulation ΔS_{MF}, though a differential module (differential time set to 200ms), plus with the current calculated thickness deviation, the trend value of thickness deviation is

$$X(k) = [\Delta t_{2,\text{MF}}(k) - \Delta t_{2,\text{MF}}(k-1)] \times \frac{\text{TD}}{\text{TA}} + \Delta t_{2,\text{MF}}(k) \quad (9)$$

The predictive thickness deviation is

$$\Delta t_{\text{Foward}} = C_0 \frac{K_S}{K_S + C_M} \times \Delta S_{\text{Foward}} \quad (10)$$

In Eq.(10), C_0 indicates effective ratio, through a differential module (differential time set to 200ms), coupled with the current calculated thickness deviation, the trend value of thickness deviation is

$$Y(k) = [\Delta t_{\text{Foward}}(k) - \Delta t_{\text{Foward}}(k-1)] \times \frac{\text{TD}}{\text{TA}} + \Delta t_{\text{Foward}}(k) \quad (11)$$

According to the D-value between the calculated thickness deviation and the actual measured thickness deviation under the two control modes, a group united dynamic weights are developed respectively in two control modes. The total value of the gap regulation is calculated after weighting. Besides, a tolerance limiter is set to ensure the security of weighting algorithm, calculation value which exceed the limiter will be failure, w_1 and w_2 remain be 1.0.

$$0 \leqslant \left| \frac{X(k) - T_{2,\text{Thg}} + t_1^*}{T_{2,\text{Thg}} - t_1^*} \right| \leqslant e_{\text{Limit1}}$$

$$0 \leqslant \left| \frac{Y(k) - T_{2,\text{Thg}} + t_1^*}{T_{2,\text{Thg}} - \text{h}_1^*} \right| \leqslant e_{\text{Limit2}}$$

$$\begin{cases} w_1 = 1 + C_1 \dfrac{\text{X}(k)}{T_{2,\text{Thg}} - t_1^*} \\ w_2 = 1 + C_2 \dfrac{\text{Y}(k)}{T_{2,\text{Thg}} - t_1^*} \end{cases} \tag{12}$$

In Eq.(12), C_1 and C_2 are constants obtained from commissioning, the principle is that sum of w_1 and w_2 approximately equal 2.0, both substitute into the Eq.(8), all AGC regulation can be calculated directly.

The rule "w_1+w_2≈2.0" ensures that the total regulation amount of AGC controller will not change abruptly, but the D-value between the monitor and mass flow regulation of two adjacent groups may be large, so it is still necessary to set a smoothing program. When step changes generated by the two groups of parameters is detected (for example the threshold value is 0.5mm), a constant rate slope smoothing unit is applied to handle the regulation components, aim at eliminate the output undulate during the parameter transition.

6 Experiment and Application Results

During indoor tests, we built a program testing platform in the laboratory environment, the L1 automation program is developed on the Siemens platform by WISDRI, including all the basic automation control function such as AGC control, tension control, HGC control, speed master control, instrument control, emulsion control, purge control, as shown in Fig.5. Besides the AGC control program and tension control program are developed in the high speed control module FM458. Taking the traditional AGC program as the program to be tested, run the improved anti interference AGC program in this paper and compare it with traditional algorithm. The results of four times simulated rolling are shown in Table 1.

Table 1 Product Thickness Accuracy of Two Control Methods

Simulation Coil	Raw Thickness	Product Thickness	Accuracy Traditional Control	Accuracy Proposed Control
1#	2.3mm	0.35mm	±7μm	±4μm
2#	2.5mm	0.45mm	±8μm	±3μm
3#	2.5mm	0.5mm	±8μm	±4μm
4#	2.1mm	0.3mm	±6μm	±3μm

Fig.5 Testing Platform in the Laboratory Environment

Further, WISDRI Engineering & Research Incorporation Ltd contracted an EPC project includes a 20-Hi cold reversing mill in Anyang City, Henan Province, 2021. The automatic control system (L1 system) is researched, programmed and commissioned by WISDRI Ltd. This particular 20-Hi mill applied new mechanical technology such as the new online push type intermediate roll shifting, has advantages such as high stiffness, high rolling speed and more compact structure, it can produce wide and thin high quality silicon strip in domestic enterprise. After three months of commissioning work, the mill is put into production in 2022, now the thickness accuracy of the final product fully meets the requirements of original design.

In the early stage, the 1300mm mill operating under the traditional AGC control, 0.495mm cold rolling coil are produced from 2.5mm hot rolled raw material after 4 pass rolling. When the line accelerates to routine rolling speed, three types AGC methods start to work in sequence, Firstly is the feed forward control, soon the mass flow and the feed forward control launched subsequently. Initial total regulation value rises greatly, the outlet strip thickness is quickly close to the set point. Feed forward and Mass flow regulation are both positive; when rolling process reach to the strip tail, the thickness fluctuation shown in Fig.2 and the emulsion concentration fluctuate appear, feed forward and mass flow regulation began mutual exclusion, which bring exit thickness gradually diverge. The final deviation is ±8μm. As the product curve shown in Fig.6a.

After applying the united dynamic weights of proposed strategy, using the same hot coil as raw material. when the line speed increase, all AGC controllers output stable regulation lasted to the tail of the coil. Final thickness deviation of the product fully meets the requirement, the thickness deviation accuracy of the final product in the routine rolling stage within ±3μm~±4μm, better than compared algorithm or even similar mill line in domestic (±5μm). As the product curve shown in Fig.6b.

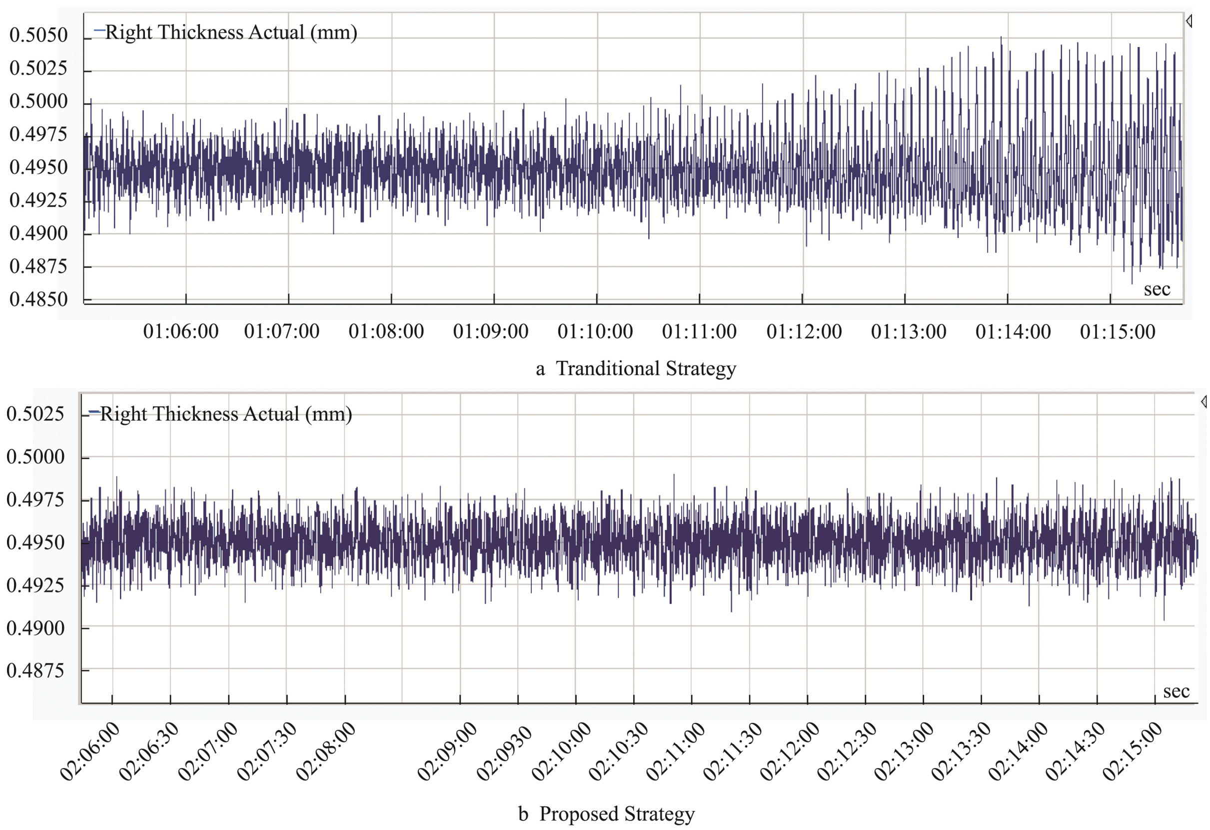

Fig.6 Product Thickness Curve

7 Conclusion

A New anti-interference strategy for automatic gauge control of 20-Hi reversing mill is introduced. A united dynamic weights algorithm of Feed forward-Mass flow is presented for the complex interference problem in automatic gauge control, the relevant control strategy is provided to eliminate the interference. Uncertainty of the raw material and emulsion system in 1300mm 20-Hi reversing mill is discussed, then united dynamic weights algorithm for final roll gap regulation is proposed, a constant rate smoother is set before the controller output are sent to actuators. As a result, the uncertainty interference in the rolling process is effectively eliminated.

The improved AGC control enhances the system availability and tolerance in practical manufacturing significantly, now it is running stably on the 1300mm 20-Hi roll of mentioned project, final product thickness accuracy achieve ±3μm~ ±4μm which has reached an leading level in domestic.

Statements and Declarations

The authors declared that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted

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