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Speed cascade control system for bar and wire rod mills

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Abstract

This paper describes in detail the basic principle and engineering implementation for material tracking, minimum tension control, loop control and speed cascade control of bar and wire rod mills.

Key words:
speed cascade; material tracking; minimum tension control; loop control

Speed cascade control is the most important part of the control system for modern profile mills. Since the distance between the stands is short and the rolling speed is fast, the control system must have high accuracy, good stability, fast speed regulation and self-adaption. Precise material tracking is the base for realizing the above requirements, the minimum tension control and loop control are the necessary methods for achieving these. The actual values of tension and loop height are obtained by detection units, these are compared with set-points, and the differences are used to control the speed of upstream stands by speed cascade system to achieve the set tension and loop height.

Material Tracking

The material tracking function provides accurate information of the current position of the billet head and tail ends proceeding through the mill. Tracking is the base requirement for an accurate automatic control sequence for main and auxiliary drives. The speed reference distribution, automatic loop control, minimum tension control and automatic cutting of flying shears in the mill line are based on precise material tracking.

Signal Source and Reliability Processing

The following signal sources are used, depending on different rolling areas:

- Hot metal detector (HMD), which is the most commonly used sensor in the mill line.
- Loop scanner, which is used in automatic loop control, and generates the signal of material tracking simultaneously.
- Stand threading signal, which is generated from the peak torque detector in the AC/DC drive unit. It is mainly used in roughing mill and intermediate mill area. It is generated when the rolling torque exceeds the nominal torque by 25%.
- Cutting signal, which is generated instantly when the blades of the flying shear is closed.

These material detection signals can only be used for the tracking function after validation is done. The primary material detection signal can be used for the real signals to update the tracking function only when the head permission or tail permission is enabled, otherwise the alarm signal of false head or false tail will be generated. The condition of head permission is that the elapsed time of material detection signal has exceeded the minimum interval time between subsequent billets. The condition of tail permission is that the detection signal of the adjacent upstream stand is not active and the elapsed time has exceeded the minimum interval time between the subsequent billets.

Basic Concept and Basic Principle of Material Tracking

The basic method of material tracking is to calculate the integral of the material speed reference over time. The HMD, loop scanner, threading signal, cutting signal are used to start and update the tracking function after passing the validation processing mentioned above.

The basic principle of material tracking:

- The material detection signals are only available for the working stands enabled in the mill configuration displayed on the HMI.
- Each working stand has its own material head and tail tracking function.
- For each working stand, the tracking function generates a stand threading signal (the “P- signal”) to indicate the material having entered the stand, and also generates three warning signals W1, W2, W3 to indicate the position of the head end or tail end having approached the roll gap of the stand. W1 and W2 are used for automatic loop control, and W3 is used for minimum tension control.
- After the tracking function generates a stand threading signal, it goes on to track the billet head end until it passes the next downstream material detector. If the tracking function predicts that the head end of billet should be at a downstream material detector, but the detector does not detect the billet head end, a cobble signal will be generated by system. In case a cobble situation is signaled, the threading P-signal and the three warning signals W1, W2 and W3 will be reset and the tracking function for the stand will be de-activated and simultaneously the upstream crop shears will be started to crop the remained material.

Tracking Procedure

When the tracking function of upstream (n-1) th stand indicates that the billet head end has entered the roll gap, the tracking of billet head for the n-th stand is started. The preset value of the length integrator is the distance *Lss* between the (n-1) th stand and the n-th stand. The distance between material head end and n-th stand is: $Lss - \int_0^t Vdt$, here V is the speed of the material head, i.e. the linear speed of the effective roll diameter of (n-1)th stand. When the material head end reaches the detector between two stands, the distance *Lms* between the detector and n-th stand is used to update the distance between the material head end and roll gap of n-th stand to $Lms - \int_0^t Vdt$; When the distance between the material head end and roll gap of n-th stand is less than the warning preset length Lw1, Lw2, Lw3, the corresponding warning signals W1, W2, W3 are generated; when the distance between the material head end and roll gap of n-th stand reaches 0, stand threading signal P is generated; The head tracking is deactivated after the tracking function indicates that the material head has passed the material detector downstream of the n-th stand for a while.

When the tracking function of the upstream (n-1)th stand indicates that the billet tail end has passed the roll gap, the tracking of billet tail end of n-th stand is started. The preset value of the length integrator is the distance *Lss* between (n-1) th stand and n-th stand. The distance between material tail end and n-th stand is: $Lss - \int_0^t Vdt$, here V is the tail speed of the material, i.e. the linear speed of entry side of n-th stand. When the material tail end passes the detector between two stands, the distance *Lms* between the detector and n-th stand is used to update the distance between the material tail end and roll gap of n-th stand to $Lms - \int_0^t Vdt$; When the distance between the material tail end and roll gap of n-th stand is less than the warning preset length Lw1, Lw2, Lw3, the corresponding warning signals W1, W2, W3 are generated; when the distance between the material tail end and roll gap of n-th stand reaches 0, stand threading signal P is reset; The tail tracking is deactivated after the tracking function indicates that the material tail has passed the material detector downstream of the n-th stand for a while.

Speed Cascade Control

Bar and wire-rod mills are continuously rolled according to the principle of metal mass flow equation, i.e., the speed relationship between stands in the rolling line is as follows:

$$V(n)=V(n+1)/(R(n)[1+K(n)]) \quad (1)$$

Where: V(n) and V(n+1) are the speed of n-th stand and (n+1) th stand respectively\; R(n) is the reduction factor of n-th stand; K(n) is the correct factor for reduction factor of n-th stand.

The minimum tension control and loop control functions work to arrive at a proper K(n) value.

Head Minimum Tension Control.

Basic Principle

The minimum tension control generally is used in where loops cannot be formed due to material dimensions being too large or distances between stands being too short, which is usually the case in roughing mill and intermediate mill areas. A change in the tension of the rolled material has a linear relationship a change on the torque of main stand motor, hence the motor torque of motor also indirectly measures the tension of rolled material. The minimum tension control system adopts the torque memorizing method to detect tension, i.e.

$$\Delta F=2i\eta/D.\ \Delta T \quad (2)$$

Where, *ΔF* is the change of tension between stands, *D* is the effective roll diameter of stand; *i* is the ratio of gearbox, η is the efficiency of mechanical drive system; *ΔT* is the changed value of shaft output torque of main motor.

The tension coefficient F_T is introduced for determining the control target of minimum tension control, the definition is as follows:

$$F_T=T_r/T_m \quad (3)$$

Where, T_r is the output torque of motor in tension-free rolling; T_m is the output torque of motor in minimum tension.

The error of motor torque in the k-th sample is as follows:

$$\Delta T(k)=T_m(k)-T_r/F_T \quad (4)$$

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The reference of tension coefficient is given from rolling pass schedule, generally it is slightly more than 1. T_m and T_r can be obtained from ABB drive system which use the direct torque control (DTC) technology, the high frequency components of sample value will be eliminated by low pass filter. The filtering time of low pass filter normally is usually set to 0.5s.

The formula (4) is the physical equation of the tension error in minimum tension control loop which employs a PID algorithm.

Torque Memorizing

The memorizing of free rolling torque T_r must follow the following sequence:

- The billet has been threaded in n-th stand.
- The billet is not threaded in the (n+1)th stand and has not entered the guide of (n+1)th stand.
- The rolling torque of billet in (n-1)th stand has been regulated to a free rolling status.
- Since the difference of billets with same specification is very small, their difference of torque in free rolling status also is not big. For the billets with same specification, T_r will adopt the weighted arithmetic average of T_r values of the last three consecutive billets.

When the billet enters the (n+1)th stand and the torque of this stand is stabilized, the torque of n-th stand is sampled; this sample value will represent the torque T_m of the n-th stand in actual rolling.

The sampling time of free rolling torque T_r and actual rolling torque T_m should be as close as possible. At the same time, the duration of minimum tension control should be less than the time for the billet to travel from next stand i.e. (n+1)th stand to the stand after the next stand, i.e. the (.n+2)th stand, so that when the torque signals still are high correlative the minimum tension control is ensured to be finished. Otherwise, the torque values will contain some disturbance signals which are not caused by tension variations, leading to errors of estimation and regulation.

Minimum Tension Control Program

The minimum tension control program with adaptability and some dead zone limit features, is shown in Fig.1.

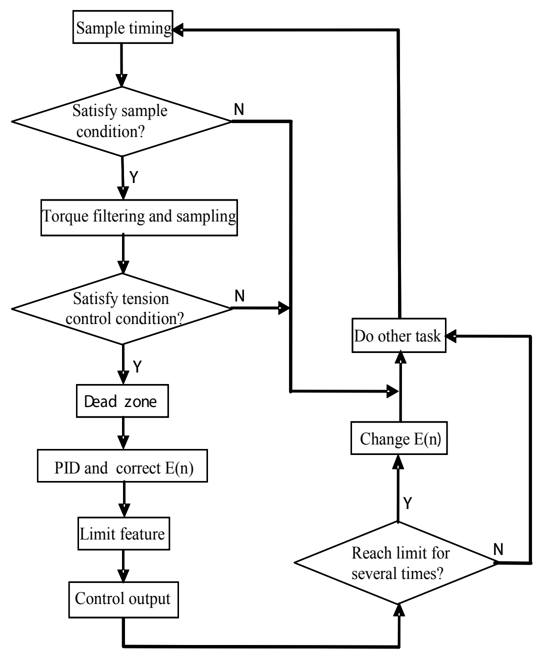

Fig. 1 Program flow chart of minimum tension control

Tension Free Control Using Loopers

Loops Length Calculation and Control Output

Loop tension free control is used where loops can easily be formed due to smaller material dimensions, usually in the pre-finishing mills and finishing mill area.

If A is the distance between loop scanner and the loop table, B is the distance between two support roll, α is the detection angle, the scanning range of loop scanner will be 2Atan(α/2). If the output voltage of the loop scanner corresponding to the maximum range is V_{max}, the actual loop height H will be: $H=2A\tan(\alpha/2).V/V_{max} - H_0$, where V is the output voltage of loop scanner, H_0 is the minimum detecting height of loop scanner.

Assuming that the shape of loop is an approximate arc, t the loop length will be approximately as follows:

$$L(k)=\pi^2 H(k)^2/4B \quad (5)$$

$$\Delta L(k)=L(k)-L_s=\pi^2[H(k)^2-H_s^2]/4B \quad (6)$$

Where, H(k) and L(k) are the respectively the loop height and loop length of the k-th time sample; L_s is the reference of loop length; H_s is the reference of loop height, set by operator; ΔL(k) is the changed value of loop length.

In control process the loop height can be controlled by regulating the stand speed. The speed regulation adopts the PID control with dead zone and limit features, i.e.

$$\triangle V(k)=\begin{cases} 0, |\triangle L(k)|<a \\ K_p \triangle L(k)+K_i \sum_{j=1}^{k} \triangle L(j), a\leq|\triangle L(K)|\leq b \\ V_a \cdot 5\%, |\triangle L(k)|>b \end{cases} \quad (7)$$

Where, $\Delta V(k)$ is the output value of speed correction; K_p is the coefficient of proportion regulation; K_i is the coefficient of integral regulation; a is the control dead zone; b is the limit value; V_a is the present material speed.

Loop Control Process

When the material tracking system detected the signal W1 of material head in n-th stand, the persuader roll is ordered to rise. The triggering time of signal W1 should ensure that the material is just about to enter the roll gap of n-th stand when the persuader roll has risen to its set position. At the same time, control system starts to correct the speed of stands according to the cascade direction, add the regulator’s output to the speed reference of (n-1)th stand, so that the loop height is maintained at the reference value. In control arithmetic, the proportion part starts immediately to make action from the threading moment of n-th stand for assisting loop forming. The integral control is enabling with a time delay after the threading of the n-th stand. Whereby the speed of n-th stand is changed by continuously modifying the correction factor K(n) of n-th stand.

When the material tracking system detected the signal W2 of material tail in (n-1)th stand, the loop lowering stage is entered with the system ordering the persuader roll to descend. First, the control system will block the integral action of loop controller and reduce the reference of loop height, only reduce the speed of stand n-1 to prevent a whiplash when the material tail leaves this stand. At the same time, the control system should avoid affecting the speed of other stands. After the signal W1 is triggered for a while, the speed correction is blocked until the material tail end leaves n-th stand.

Conclusion

The project practices have proved that the control system described in this paper can fully meet the requirements of technology, it can reduce the commissioning time and accidents in the rolling process, improve the production efficiency and product quality.

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