Research on Correlation of Rolling Force and Monitoring Automatic Gauge Control Systems

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Abstract: - It's possible for different kinds of automatic gauge control (AGC) systems working simultaneously to impact and disturb each other while adjusting their moving directions. In order to implement a decoupling control, we modified the parameters and structure of the AGC system in a hot rolling mill. As a result, it was proved that theoretically, gauge meter type AGC system and monitoring AGC system could be independent of each other by computer simulation and mathematics models, namely, decoupling control of these two AGC systems was realized in the true sense.
Keywords: - Automatic gauge control, rolling force AGC, monitoring AGC, correlativity analysis

1 Introduction

Recently, the accuracy of hot strip gauge is strictly demanded, and the strip thickness becomes the most important quality in hot strip rolling. It is well known that the accuracy of final strip thickness in the hot strip mill depends on the gauge control performance at each stand. In order to improve the quality of the hot strip gage and to reduce the strip thickness deviation, the Automatic Gauge Control (AGC) system now is widely used in modern hot strip mills of the world. Gaugemeter type automatic gauge control (GM-AGC) system, which controls the thickness of strip rolled by rolling force signal to measure strip's thickness indirectly, has been applied extensively in strip rolling mills [1], because of its advantages such as sample installations, rapid response and so on. However, GM-AGC can only eliminate the deviation of strip exit thickness caused by the change of strip entry thickness, but not those caused by either eccentricity, abrasion, expand with heat, and shrink from cold of rollers, nor the different thickness of bearings' lubricating oil membrane aroused with rolling speed change. In order to achieve better thickness precision, GM-AGC always was applied with the help of monitoring AGC, which control strip exit thickness by adjusting rolling gaps according to the deviation thickness measured directly with gaugemeter equipments. Therefore, it is possible for them to disturb and influence each other if several kinds of AGC systems with different principles work together at the same time.

2 Rolling theory of steel strip

Strip thickness h on the delivery side of the rolls is equal to the work-roll gap under load if the elastic deformation of the material is excluded. As given by (1), h is the sum of S_0 and ΔS, S_0 being the work roll gap without load and ΔS the amount of deformation of the rolling mill under load. The ΔS is given by rolling force P divided by mill modulus M, so the strip exit thickness is dependent upon the rolling force. The ΔS, which is of the order of millimeters, cannot be neglected when calculating the strip exit thickness. Equation (1) is shown by curve (a) in the Fig. 1, which is called the elastic deformation curve of the mill.

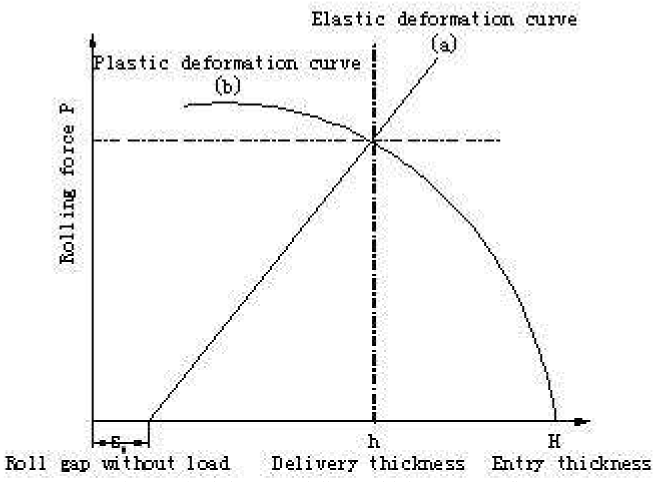

Fig. 1 Principle to set delivery thickness (P-H figure)

During rolling, the rolling force and the strip exit thickness always change if some variation occurs in the roll gap, the mean deformation resistance caused by a variation in speed and temperature, or the entry side strip thickness. In other words, a change in the strip exit

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thickness can be instantaneously detected by monitoring the rolling force. When the rolling force changes, the strip exit thickness can always be kept constant by adjusting S_0 in (1) with the amount required to compensate for the rolling force difference. This is the principle of automatic gauge control (AGC).

$$h = S_0 + \Delta S = S_0 + \frac{P}{M} \quad (1)$$

3 Relativity analysis of GM-AGC and Monitoring AGC system

GM-AGC and Monitoring AGC systems constituted mainly thickness control system of one hot rolling mill in an iron and steel plant.

There was only GM-AGC from stand 1 to stand 3, and there were not only GM-AGC but also Monitoring AGC from stand 4 to stand 7. Therefore, we should discuss the decoupling control of AGC system in the latter 4 stands, which automatic control block diagram of AGC system is shown as Fig.2.

Where ΔS is the increment of the work-roll gap based on roller's position locked, and ΔP is the increment of rolling force based on roller position locked. S^* is the input of automatic position control (APC), and ΔS^* is the adjustment of the work-roll gap in order to eliminate exit thickness deviation Δh_c. α is mill modulus control (MMC) coefficient. M is mill modulus, and Q is strip plastic deformation modulus. G(s) is integrating transfer function of the work-roll gap adjuster of position control system, servo valve and mill system. $G_1(s)$ is equivalent transform function.

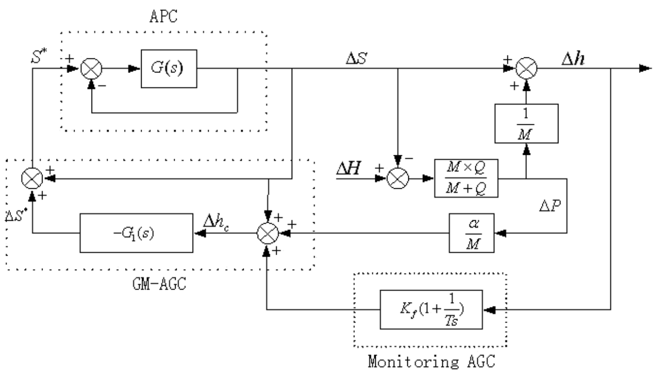

Fig. 2 Strip thickness automatic control system

As shown in Fig.2, adjustment of automatic position control (APC) is as follows:

$$S^* = \Delta S^* + \Delta S = -G_1(s)\Delta h_c + \Delta S$$

$$= \Delta S - G_1(s)[\Delta S + \frac{\alpha Q}{M+Q}(\Delta H - \Delta S) + K_f(1+Ts)\Delta h]$$

$$= [1 - G_1(s)\frac{M+(1-\alpha)Q}{M+Q}]\Delta S - \frac{\alpha Q}{M+Q}G_1(s)\Delta H$$

$$-G_1(s)K_f(1+Ts)\Delta h] \quad (2)$$

Where the third part of (2), i.e. $-G_1(s)K_f(1+Ts)\Delta h$, is the effect of monitoring AGC working alone. The second part of (2), i.e. $-G_1(s)\Delta H\alpha Q/(M+Q)$, is the effect of GM-AGC working alone. The first part of (2) is the effect of GM-AGC and Monitoring AGC working together. The real meanings of (2) are described as follows:

On the assumption that there is a deviation ΔH of strip entry thickness sometime, GM-AGC system will work to adjust the work-roll gap with the amount of ΔS, which is equal to $-G_1(s)\Delta H\alpha Q/(M+Q)$ according to the deviation ΔH of strip entry thickness. As a result, the strip exit thickness should be equal to the locked thickness of GM-AGC in theory. If the locked thickness valve is right and the MMC coefficient α is equal to 1.0, the deviation Δh of strip exit thickness should be equal to zero, namely the third part of (2) equaling zero, which means monitoring AGC needs not to work any more. In fact, the MMC coefficient α, at most time, isn't equal to 1.0 and the locked strip thickness valve often isn't also right because of calculation error of mill's modulus M and strip plastic deformation modulus Q, which will lead to a stable strip thickness deviation in the exit side of the rolling mill, namely the third part of (2) may not equal zero, so the monitoring AGC must take effect to adjust the work-roll gap of mills in order to eliminate the deviation of strip exit thickness, and the adjustment of the work-roll gap should be equal to the third part of (2). The first part of (2) is the adjustment process of GM-AGC and monitoring AGC working together.

According to the steel rolling theory, we know that the work-roll gap should be changed to an adjustment equaling $\Delta h(M+Q)/M$ if there is a deviation Δh of strip exit thickness, in other words, $G_1(s)$ may be equal to $(M+Q)/M$. However, it is obvious that the first part of (2) isn't equal to zero in this case while α is not 1.0, which means GM-AGC and monitoring AGC will disturb and influence each other when $G_1(s)$ is equal to $(M+Q)/M$. Now, we let the first part of (2) be equal to zero, namely the adjustment process of GM-AGC and monitoring AGC working together is equal to zero, so GM-AGC and monitoring AGC can wok respectively, which means to realize decoupling control of two AGC systems really. Based on analysis above, we can let

$$[1-G_1(s)\frac{M+(1-\alpha)Q}{M+Q}]\Delta S=0 \tag{3}$$

The work-roll gap should be adjusted because the deviation Δh of strip exit thickness must be eliminated, namely ΔS should be not equal to zero. That is to say,

$$1-G_1(s)\frac{M+(1-\alpha)Q}{M+Q}=0 \tag{4}$$

namely,

$$G_1(s)=\frac{M+Q}{M+(1-\alpha)Q} \tag{5}$$

4 Meanings of transform function $G_1(s)$ in theory

In practice, different control goal requires different mill modulus in the manufacture process of hot rolling mill. It lies on restraining the disturbances inside or outside of the rolling mill mainly, regulating strip thickness using the work-roll gap or strip tension and controlling strip thickness precision or better shape quality. Hydraulic automatic gauge control (AGC) can make elastic deformation of the rolling mill get some compensation to a certain extent as soon as rolling force has some fluctuation. In other words, the roll gap can get different compensation even if rolling force deviation is the same. This is equivalent to say the mill modulus can be controlled. So, there is a concept of the mill modulus control (MMC) to be brought forward. According to different requirement of rolling technology, different equivalent mill modulus can be obtained while changing adjustment coefficients in the AGC system.

The increment form of (1) is as follows:

$$\Delta h_c=\Delta S+\frac{\Delta P}{M} \tag{6}$$

MMC is to change (6) into:

$$\Delta h_c=\Delta S+\alpha\frac{\Delta P}{M} \tag{7}$$

So, we can get different elastic increment of rolling mill with different α, even if the force sensor monitors the same rolling force.

If there is an entry thickness deviation, AGC system work balance place (S_l, P_l) will shift to (S, P) in order to keep exit thickness from deviation. So, it is easy to know:

$$\Delta S=S-S_l \tag{8}$$

$$\Delta P=P-P_l \tag{9}$$

In order to eliminate this deviation, the increment of rolling force is given as follows:

$$\Delta P_s^*=-\Delta S\frac{MQ}{M+Q} \tag{10}$$

Work-roll gap adjustment can be gotten from (7) and (10).

$$\Delta S^*=-\frac{M+Q}{M+(1-\alpha)\times Q}\times\Delta h_c \tag{11}$$

According to ΔS^* the input adjustment of APC is:

$$S^*=-\frac{M+Q}{M+(1-\alpha)\times Q}\times\Delta h_c+\Delta S \tag{12}$$

Equations (7), (10) and (11) are the basic of mill modulus control GM-AGC system.

Based on the analyses above, automatic control block diagram of its AGC system is shown in Fig. 3.

Where:

$$G_1(s)=\frac{M+Q}{M+(1-\alpha)\times Q}$$

It is the same as (5).

5 Simulation of GM-AGC and monitoring AGC working together

Let M=5000 N/m, Q=4000 N/m. Assuming that there is a deviation of strip exit thickness, which is equal to 100 μm, because of calculation error of GM-AGC system, and suppose that there is a deviation ΔH disturbance of strip entry thickness, which is equal to 45 μm, at t=0.2s while monitoring AGC are taking effect in order to eliminate the deviation (100 μm) of strip exit thickness, computer simulation and analysis based on mathematics modeling were made with MATLAB, which generated results as follows.

There are 5 curves in the simulation figures, of which the upper blue curve and red curve represent the simulation while the GM-AGC works alone, the lower blue curve and red curve represent the simulation while the GM-AGC and the monitoring AGC work together, and the green curve represents the simulation while the monitoring AGC works alone. As given by computer simulation curves, we can draw following conclusions: (1) GM-AGC has enough ability to eliminate the deviation of strip exit thickness caused by the change of strip entry thickness (relative to the locked thickness of GM-AGC). (2) In order to eliminate the deviation of strip exit thickness, it needs monitoring AGC to take effect if there is deviation between locked strip thickness and strip exit thickness because of errors of mill modulus and strip plastic deformation modulus. (3) When GM-AGC works with monitoring AGC, the whole result is equivalent to parallel shift of the result of GM-AGC working alone, and its response time and speed doesn't change at all. Therefore, monitoring AGC has nothing to do with GM-AGC. In other words, decoupling control of two AGC systems is realized truly in this case.

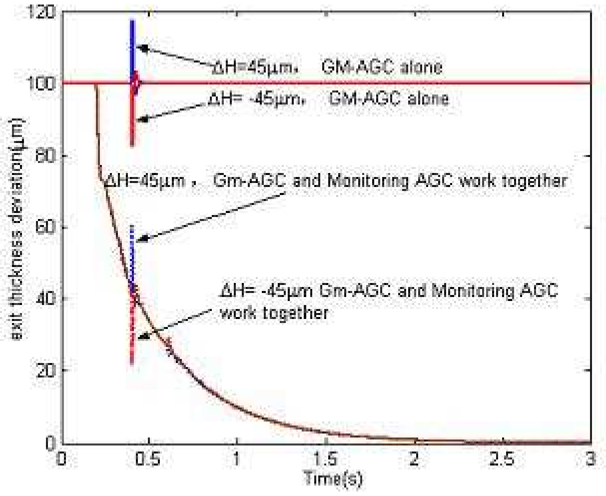

Fig.3 Simulation of GM-AGC and monitoring AGC working together

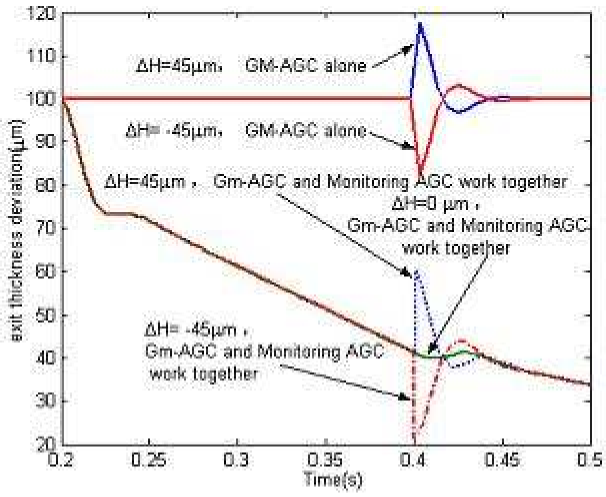

Fig.4 Simulation of GM-AGC and monitoring AGC working together (zoom in)

6 Conclusions

It has been a very universal method to adopt MMC in hot rolling mills. Some control parameters of AGC system must be changed resoundingly owing to MMC coefficient introduced into AGC system. If control parameters are set still according to traditional transform relations, it will be possible to cause disturbance and influence between different kinds of AGC systems, bringing about actions in contrary directions when the work-roll gap is adjusted. As a result, it is easy to cause vibration and instability of rolling mills. On the contrary, GM-AGC and monitoring AGC will work independently if control parameters and structure of the AGC system are designed properly. In other words, decoupling control could be realized in the real sense between GM-AGC system and monitoring AGC system this way.

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