Quality prediction and control of tube hollow

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Abstract: The quality prediction of tube hollow model based on the variance staged multiway partial least square (MPLS) method was proposed. The key aspects of staged decomposition of the productive data, calculation of the variance value, modeling, and on-lined prediction in the variance-staged MPLS method were introduced. Based on the model, iterative optimal control method was used for quality control of tube hollow. The experimental results show that the obvious benefits of this method are low maintenance cost, good real time function, high reliability precision, and practical application to on-line prediction and optimization on the quality of tube hollow.

Key words: seamless tubes; cross piercing; tube hollow; quality control; variance-staged multiway partial least square (MPLS); iterative optimal control

1 Introduction

Since seamless tubes are mainly used in the industries of petroleum, aviation, cars, national defense, and city public facilities, their quality is of great importance. The production of seamless tubes is strictly supervised at each stage, because waste products or substandard products may be produced at any stage and once such deficiencies are not detected in time, the utilizing efficiency of equipments will be affected and waste of energy will be caused in the later producing procedures [1–3].

The billet piercing process is the first procedure of the figuration of seamless tubes, and the quality of tube hollow after piercing will greatly affect the quality of the final products. This process is a multi-stage, complex, non-linear and dynamic multi-variable batch process, which makes the quality of tube hollow and the process variables more complicatedly related. The quality of tube hollow can hardly be timely measured in practice because of the continuity of the producing process and the limitations on monitoring instruments. The quality control is achieved by the staged random sampling through the workers’ regulation on processing parameter according to their experience. Certain relations were built between the processing parameters and the quality information like tube hollow deformation, twist, inner and outer cracks and surplus strain based on the element method [4–6]. But it was hard to build the corresponding projective relationship between the processing parameters and the quality parameters one by one. Based on the BP neural net method, the relation model was built between the tube hollow qualities and the processing parameters like roller shape, feed angle and plug advance; however, the accuracy of the quality model was relatively low because of the limitations on modeling method and processing parameters.

In the quality prediction of batch process, the multiway principal component analysis (MPCA) method, the MPLS method and its improved method were usually adopted [8–12]. The traditional application of MPCA method and MPLS method to on-line supervision depended on the prediction on the future data point of the process-surveying variable. LU et al [8] proposed three prediction methods on the data left after reactions, but all of them did not take account of the dynamic relation between the sampling data, and the prediction error was rather obvious. The proposition of building multi-MPCA model [9–10] solved the problem of predicting the future data point, but it was more adaptable in application to fault diagnosis, since the formation of tube hollow was a continuous process and it was hard to be expressed by any sub-stage prediction model.

Tube piercing can be divided into three sub-stages: the first unsteady piercing stage, the steady piercing stage and the second unsteady piercing stage. The quality prediction model for the tube hollow based on the variance...
staged MPLS was proposed. In this method, the process variables were classified by piercing stages and the variance value of the relative variables at each stage was taken as input variable. This method can overcome the defects of complex structure and extensive calculation of the traditional MPLS model, solve the problem of the insensitivity of the prediction model to the minor fluctuation of the variables in the batch process, avoid the disadvantage of data unevenness in the modeling and predicting process, and make the tube quality on-line modeling and predicting applicable.

2 Factors affecting tube hollow quality

The factors that affect the tube hollow quality should be firstly analyzed to avoid information deficiency or redundancy in modeling and therefore to insure the accuracy of the prediction model. Through the technical feature analysis, it is known that the variables at different stages will exert different influences on the tube hollow quality. Some variables only exist and work in a certain stage, while others exist throughout the whole producing process and greatly affect the tube hollow quality. In the practical producing process, the billet piercing process can be mainly divided into three stages: the first unsteady piercing stage, the steady piercing stage and the second unsteady piercing stage.

The first unsteady piercing stage begins with the touch between the rolled piece and the rolls, and ends when the metal fully fills the deformation zone. The variables that affect the tube hollow quality at this stage include: the entry temperatures of the upper roll and the lower roll, the reductions of the upper roll and the lower roll, the inclinations of the upper roll and the lower roll, the rotation speeds of the upper roll and the lower roll, the billet pusher position, the practical thrust dolly position and the mandrill position.

The steady piercing stage begins when the metal fully fills the deformation zone and ends when the billet leaves the roll. In comparison with theVisually unsteady piercing process, the variables in relation with the tube hollow quality exclude the entry temperatures of the upper roll and the lower roll.

Quantitative index of the tube hollow quality is needed in quality evaluation. As its quality is mainly reflected by the tube shape and the inner structure, and the latter one can only be measured through the stock jamming and hydraulic testers to the pipes, the tube shape is only chosen to carry the quality analysis. The wall thickness accuracy of hot-rolling seamless tubes, especially the transversal thickness unevenness, is a very important tube hollow quality index [13]. The transversal thickness unevenness is defined as the ratio of the maximum thickness deviation to the nominal thickness:

\[ \Delta S_T = \frac{\delta_{\text{max}} - \delta_{\text{min}}}{\delta_{\text{HOM}}} \]  

where \( \Delta S_T \) is the relative transversal thickness unevenness; \( \delta_{\text{max}} \) is the maximum tube wall thickness; \( \delta_{\text{min}} \) is the minimum tube wall thickness; \( \delta_{\text{HOM}} \) is the nominal tube wall thickness.

The longitudinal thickness unevenness is the differential value between the mean value of the front-end tube wall thickness and that of the back-end tube wall thickness:

\[ \Delta S_L = \frac{\sum_{i=1}^{n} \delta_{i,f} - \sum_{i=1}^{n} \delta_{i,b}}{n} \]  

where \( \sum_{i=1}^{n} \delta_{i,f} \) and \( \sum_{i=1}^{n} \delta_{i,b} \) stand for the measured sum of the front-end and the back-end tube wall thickness, respectively, and \( n \) is the sum of points measured at each end [14].

3 Predication modeling method for tube hollow quality

3.1 Modeling method

As analyzed above, tube hollow quality is affected by many factors. It might be predicted online and therefore controlled timely through building the relation model of the tube hollow quality and the related factors. Since there are adequate process data and easy, accurate testing method on spot, statistics method is adaptable for modeling. The Multiway PLS (MPLS) model proposed by NOMIKOS and MACGREGOR is a well-known, effective tool of batch process statistics analysis, modeling and quality prediction [15–16]. But like the process supervision based on the MPCA model, the quality analysis and on-line prediction based on the MPLS model are not adaptable to the multi-procedure or multi-stage batch process, because the change of process behavior in the batch operating period can hardly be