Application of Neural Networks to Cold Rolling Continuous Processes for fault detection and diagnosis

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Abstract

The continuous annealing process line is effective in producing high quality cold-rolled metal strips. The process line operates at high speeds. At such speeds, the tension profile of the strip needs to be controlled in order to prevent faults such as strip breaking or slippage. But, tension cannot be measured continuously along the line as only a limited number of sensors can be placed. So it is essential that the tension is estimated correctly to a sufficient degree of accuracy. The previous works focused only on modeling the system mathematically based on system parameters. But, they ignored the effects of non-linearities such as temperature of strip, gas flow etc. which are very difficult to model. This work takes up data-based approach to address those shortcomings and to come up with the estimation of the difference between the tension estimated from model-based approach and the actual tension, in order to reduce the error significantly. This hybrid approach has also been applied in real scenario and has been found effective.

Index Terms - Neural Networks, Principal Component Analysis, Data-based approach, Annealing Process

1 Introduction

Annealing process is carried out in order to improve mechanical properties of a material. In this process, material is heated above a certain temperature (known as recrystallization temperature), and then cooled down to room temperature. This helps in relieving residual stresses, thereby imparting softness and ductility to the material. Usually when metal plates are cold rolled into thin strips, residual stresses develop, which could later be the reason for development of cracks as the strips are put into use. This is where annealing helps and prevents such a situation.

In continuous annealing process line, there is a continuous supply of strips in and out of the line. The strips enter from one end, and are heated up as they pass through a furnace zone. Then they are cooled in air and later wound on a roll. The strip is cut to desired length after winding and then sent for storage. This process produces high quality cold rolled strips.

During this process, the tension in the strip is the most important parameter that needs to be controlled. The strip runs at high speed. So, if tension becomes abnormally high, the strip can break. There is a chance of slipping of the strip between rolls if tension on both the sides of the roll is not the same. Therefore it is essential to estimate the tension throughout the strip length in order to avoid such faults.
The existing work in this field is based on model-based estimation of tension profile. A limited number of tension sensors were used to measure tension. Then a mathematical model of tension profile was prepared taking into account the speed of the rollers, measured tensions and currents in motors driving the rollers, as the system parameters. However, the effect of temperature, gas flow in furnace, strip inertia, bearing friction and roller eccentricity on tension was not included in the model because these being non-linear, are very difficult to be incorporated into the model.

This paper takes up data-based approach using Neural Networks together with Principal Component Analysis (NNPCA) to address these non-linearities. The data-based approach is combined with model-based approach to correctly estimate the tension. This way faults can be detected and diagnosed with less error, and damage to the machinery can be minimised.

2 Selection of Parameters for Data Collection

The data-based approach as the name suggests, requires collection of data of various measurable parameters of the system. These parameters should form an exhaustive set in the sense that all the factors affecting the tension are taken into account. Therefore, the list of those factors stating the parameters on which the former entities can have dependance, is presented below.

2.1 Effect of variation in Strip Temperature on Tension

1. The strip tension (F) depends on the elasticity (E) of the strip material, which in turn depends on strip temperature ($T_s$). This dependance was not considered in the mathematical model. [1]

2. The variation in strip temperature ($\delta T_s$) causes expansion and contraction which definitely affect tension. This variation depends on flow speed ($v_f$) of several fans (relative to roll speeds ($v_r$)) and furnace temperatures ($T_f$). [1]

Hence, F depends on $\delta T_s$ via $v_f$, $v_r$, $T_f$, $T_s$. This relation is unknown and nonlinear.

2.2 Effect of Gas flow on Tension

In the furnace zone, combustion process and the cooling fans cause gas flow. This flow generates friction force when gas flows past the strips which are being rolled on at high speeds. This friction $F_f$ depends on $v_f$ relative to $v_r$ and the cross sectional area of the strip (S). [1]

This relation is difficult to model mathematically and therefore taken as unknown non-linear relation.

2.3 Effect of Bearing Friction in rolls on Tension

Bearing frictions are considerable at high roll speeds and depend non-linearly on $v_r$.

2.4 Effect of Strip Inertia on Tension

In modeling the dynamics of the system, it is observed that the inertia forces affect the strip tension. But the previous model did not consider strip inertia. [1] The current hybrid approach includes this in the model. The strip inertia is therefore not required to be part of data-based estimation. [1]
2.5 Effect of Roll Eccentricity on Tension

The rolls can have two kinds of eccentricities -

1. The cross-sectional shape of the roll may be an ideal circle. But the actual axis of rotation may not coincide with the geometrical axis of the roll (manufacturing defect). This will create periodic fluctuations in tension due to variable distance of the rotation axis from the strip line.

2. The cross-sectional shape of the roll may be somewhat elliptical. This will again contribute to the periodic fluctuations in the strip tension. [1]

This is taken care of by including it in the model-based portion wherever possible and is ignored in others.

Therefore, it is clear that the parameters influencing the factors affecting tension are -

1. Roll speeds $v_r$,
2. Fan speeds $v_f$,
3. Strip temperature $T_s$,
4. Furnace temperature $T_f$

The data collection will be done for these parameters and tension compensation will be estimated based on them using Neural Networks combined with Principal Component Analysis (NNPCA).

3 Tension Compensation Estimation using NNPCA

The data collected as mentioned above is first filtered using Principal Component Analysis (PCA), so that the correlated parameters are thrown out and only the salient parameters of the system remain. Then these salient parameters are passed into the Neural Network (NN) as inputs. This NN has one hidden layer other than the input and the output layers. The activation function for hidden layer neurons has been taken as sigmoidal and for the output layer neurons, linear activation function has been chosen. Back-propagation method has been used to train the synaptic weights of the NN. Once the NN gets trained, it is capable of estimating tension compensation to good accuracy. This way the error in the tension estimated using the model based approach is compensated and the overall error gets reduced significantly.

4 Fault Detection based on estimated Tension

Fault occurring in the system could be of two types- strip breakage and slippage over the rolls, both of which are undesired. To detect the fault, after the tension profile has been estimated, the difference (called tension residual) between the measured tensions and the estimated tensions at the locations of tension meters is calculated. If the difference goes beyond a certain threshold, it implies a fault. To confirm it, the variance of this difference is calculated over all the tension meter locations. If the variance exceeds a certain threshold, the fault with large tension fluctuation is confirmed.
5 Fault type Diagnosis

If tearing in the strip takes place along machine direction, there will be huge disturbances produced when the faulty region of the strip hits the rolls. As this faulty region passes over one roll after another, this disturbance occurs in periodic fashion. Therefore, if the tension residual fluctuates with the same time period as is the time required for the strip to pass between two adjacent rolls, the fault is diagnosed as strip breakage. If not, then the fault is of other kind i.e. the slippage over the rolls.

6 Industrial Application

This hybrid approach of tension estimation, fault detection and diagnosis was applied in a real scenario of Continuous Annealing Process Line in China effectively. A considerable reduction in error in estimating the tension was found. As a result it was influential in preventing large damage as fault could be detected and diagnosed early.

7 Conclusion

The data-based approach of estimating tension compensation has been effective in addressing the shortcomings of model-based approach. The model-based and data-based approaches combine well together to make hybrid approach which has proved to be a success in the area where non-linearities in the system could not be modeled mathematically.

References