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Research paper

Review on Roll Pass Model for Tandem Cold Rolling Mill

Bibhuti Bhusana Mishra

Department of Mechanical Engg, SOA(Deemed to be University),Bhubaneswar, India
**Corresponding author E-mail: bibhutimishra@soa.ac.in*

Abstract

Cold rolled products need strict product quality with respect to uniform gauge, good shape, and dimension. Factors affecting quality are inhomogeneous composition of steel due to non uniform distribution of alloying elements, interstand tension, and variation in pressure and co-efficient of friction. In addition to it, variation in input gauge, bending of work during roll affect quality such as flatness of the strip , uniform gauge , along the length as well as across the width. Efforts have been made in optimization of various parameters, like power consumption, mill balance control, estimation of deformation parameter and roll bending measurement and intermediate roll shifting, and finally validation through measurement. Even though there has been improvement with respect to process automation, still there exists the need for 3D mathematical modeling of cold rolling process, with fast computational facility with huge data storage system. This paper presents the progress in this field.

Keywords: *Cold rolled sheet; Gauge variation; Optimization; Power minimization; Shape variation*

1. Introduction

Cold rolled products need strict product quality with respect to uniform gauge, good shape, and dimension. Factors affecting quality are inhomogeneous composition of steel due to non uniform distribution of alloying elements, interstand tension, and variation in pressure and co-efficient of friction. In addition to it, variation in input gauge, bending of work during roll affect quality such as flatness of the strip , uniform gauge , along the length as well as across the width. Efforts have been made in optimization of various parameters, like power consumption, mill balance control, estimation of deformation parameter and roll bending measurement and intermediate roll shifting, and finally validation through measurement. Even though there has been improvement with respect to process automation, still there exists the need for 3D mathematical modeling of cold rolling process, with fast computational facility with huge data storage system. This paper presents the progress in this field.

2. Empirical Study

Basic rolling model : Most of the researcher have utilized Bland and Ford (1948) cold mill model to estimate load and other parameters for tandem mill. As proposed by Bland and Ford, the input strip creates three no of zones in the arc of contact while passing through the work rolls. At the entry zone, the strip is elastically compressed till the yield stress condition is achieved. In the middle zone, the strip is plastically deformed to a minimum thickness. In the last zone, elastic recovery takes place.
One dimensional hot and cold rolling theory ,known as “slab model “is widely used, considering homogeneous deformation , Rowe(2). The assumptions used in evaluation of roll pressure in cold rolling are described below, with actual observation

1. Plane strain condition: This is reasonable with low friction. But, if friction is high, direction of principal stress may not lie in assumed direction..
2. Homogeneous deformation: If friction is high, or a very light pass is given, surface layer will deform more than central layer.
3. Constant magnitude of friction: It varies, and It is not easy to measure. However, co-efficient of friction can be assumed constant if its value is small.
4. Constant radius of curvature of of rolls: In the ID model, it is assumed that rolls are rigid. But, in practice, rolls deform elastically during rolling. Hitchcock had suggested a formula for calculating change in roll radius, considering Hertz’s theory of elastic deformation between two elastic cylinders in contact.
5. Neutral point is a straight line: But, in actual case it is an area.

Hence, in reality, cold working results in an increase in strength, hardness and decrease in ductility, elastic deformation of roll, chatter mark due to vibration. Therefore, it calls for optimization of variables in rolling, and final validation with experimental readings.
Further, rate of straining material, i.e. deformation velocity, has three main effects in metalworking, (a) Flow stress of metal increases with strain rate (b)temperature of work piece increases due to adiabatic heating,(c) there is improvement in lubrication at the tool-metal interface, Dieter (2).

3. Literature Review and Approaches to Modeling.

In order to improve quality of product, to minimize power, to minimize rolling cost, to reduce chatter mark, to maximize throughput, etc. different optimization approaches have been taken up by various authors.

3.1 Maximization of Production Rate.

Avitzur(4) had optimized rolling reduction in each stand of tandem mill, by maximizing the production rate subject to certain constraints. The objective function was maximization of the rate of production. Variables were tension, thickness of material , speed of the mill. He had used method of successive approximation as the tool for getting result.

3.2 Minimization of Power and Deformation of Roll

S.S.Rao & A.Kumar (12) had considered two objectives,(i) minimization of the power required for rolling and the minimization of the deformation of rolls considering single pass rolling(ii) minimization of sum of deflections of all the rolls through tandem mill. The radius of the rolls and the front and back tensions are taken as design variables. Constraints are location of the neutral point, and the angle of bite.
His findings are as follows: As far as thinner strip is concerned, tension is more effective in improving the quality of thinner strip. For thicker strip, increase in roll radius favors quality. Further, with limited power availability, power supplied through tension stands as a better option.

3.3 Minimization of Power

N.Venatesh Reddy & G.Suryanarayan(5) estimated reduction schedule for minimization of power. Thickness reduction schedule is distributed in various stands by assuming arithmetic, geometric, harmonic, quadratic series. It is found that power consumption is minimum, when reduction is distributed in harmonic series. Further, this simulation on power consumption was found to be less, as compared to actual measurement, which was published by Roberts.
M.Abdul Samad, Ravi S. Rao(10) had estimated the optimal no of passes in rolling ,so that addition of energy consumed by each stand becomes minimum. The model objective function was the sum of objective function of each pass, considering different constraints. The design variables were roll radius, back tension, front tension.
Specifically neutral zone was considered as region, rather than as a point (which is considered normally by other authors). And also roll flattening was taken into consideration.
Sequential Quadratic Programming (SQP) was used. It was assumed that roll pressure was a function of friction factor, also friction stress was proportional to normal stress at low pressure, and friction stress was constant at high normal pressure, and at intermediate range, shear stress increased smoothly.
Considering equilibrium of forces around a input coil, a linear first order differential equation was derived. The neutral zone was considered to exist over a zone, as against normal assumption of single point. Accordingly, length of adhesive zone was determined. Sequential Quadratic programming was utilized for above purpose. They had assumed roll pressure to be a function of friction factor. At low pressure, friction stress was considered proportional to normal stress. At high normal pressure, friction stress was constant and at intermediate range, ratio increased smoothly.
Step-1**:** Theoretical Analysis . An element of slab was considered. Principle of equilibrium of forces led to formulation of first order linear differential equation. The neutral zone was considered to exist over a zone, as against normal assumption of single point. Accordingly, length of adhesive zone was determined.
Step-2: Numerical Calculation. Fourth order Runga Kutta method was applied for integration over whole arc of contact. For finding deflection, beam deflection theory was applied. As usual, angel was fixed where strip velocity was equal to roll velocity. The expression derived by Ford, Ellis, & Bland was utilized to find out neutral angle. Basing on these experiments, roll force, roll torque, and energy required were estimated.
Considering total energy consumed as objective function, optimization was carried out for both hot and cold rolling , and graphs were plotted for energy consumption vrs no of passes, and also vrs different co-efficient of friction.

3.4 Minimization of Effect of Rolling Variable

Akira Murkani, Makishi Nakayama & others (6) had proposed pass scheduling in two stages. First one is Robust Pass Schedule Optimization (RPSO) before rolling, which works out through usual theoretical estimation of mill schedule, based upon strip properties, inter-stand tension, deformation resistance etc. The other part is Mill Balance Control (MBC). This takes care of unpredictable situation arising out of variation in rolling . As rolling starts, MBC regulates stand exit gauge tension between stands etc. Role of MBC is to act in dynamic situation by incorporating a loop into automatic gauge and tension control.
Upon comparison with an actual mill data, an 8% decrease in off gauge length and 2.4% increase in maximum speed are observed. There is no deterioration in gauge accuracy.
J. Larkiola, P. Myllykoski, J.Nylander, A.S. Korhonen,(7) had incorporated neural network theory into rolling package. The friction between roll, and sheet and deformation resistance of material was determined from measured rolling parameters and material, by applying Bland- Ford-Ellios(BFE) roll force model, and artificial network model(ANN). Measured data over 6000 coils were utilized to train ANN.
Estimation of rolling force using BFE needs an accurate knowledge on deformation resistance of the material. Even a low variation of alloying element in steel can bring an impact on deformation resistance, which impacts variation in rolling force. In many cases, it poses difficulty to carry out tensile test for each coil to determine deformation resistance. One way to estimate deformation resistance is to calculate strength of steel by using BFE model. This data was used to train the neural network. In this study, data for about 100000 coils were collected and used for above purpose.
As rolling initiates, material strength increases from entry to exit side, due to work hardening. Hence, it creates difficulty to estimate strength of behavior of material.
Also as rolling initiates, material's strength increases from entry to exit side, due to work hardening. Hence, it creates difficulty to estimate strength of material. Therefore, a mean value is normally considered by taking 40% of reduction before and 60% of after rolling pass.
So a step was taken to estimate deformation resistance, which was further used to train neural network. Friction parameter was solved by backward computation for BFE model. Deformation resistance of material was estimated by K=A+rB, where A and B value were arrived at by neural computing, and r was reduction. In this study, data for about 40,000 coils had been collected. , and used for this purpose.

3.4 Maximization of Throughput and Minimization of Operating Cost.

D.D.Wang, A.K. Tieu(8) had prepared 3 nos. of cost function , power distribution cost, tension cost, flatness (shape) cost. Then Genetic Algorithm(GA) was applied to optimize the schedule. While estimating power distribution cost, power at each stand was calculated considering uniform power distribution and consistent flatness condition. Tension cost function estimation was based upon keeping the inter-stand tension midway between upper and lower limit. Maximum value of the measured noise guided lower limit, while skidding and tearing condition guided upper limit. Optimum shape function was arrived at when strip was uniformly passed through. This happens when incoming strip profile matches with outgoing strip profile..Numerical experiment had shown that result was more promising than those from empirical formulae.

Set-up optimization C.T.A. Pires, H.C. Ferreia, R.M.Sales (9) had prepared a process optimization model in Cosipa cold rolling mill. It is a four high, four stand Tandem mill. It is equipped with four levels of automation, lowest being customer order and highest being process model.
Level 3: It is production planning level. It deals with customer order and decides priority for rolling. A batch of rolling order is executed at one set up. A good tonnage of same size order is preferred.
Level 2 : It is process optimization level. Mill set up is activated by looking at outlet and inlet data specification. Based upon this information, optimum procedure and a closed loop is set up.
Level 1: It is process dynamic control. Control signal is generated, taking reference signal from level 2 and measured process signal. This signal activates the actuator. This level includes dynamic model.
Level 0 : It deals with sensor and actuator. This level includes sensor, motor drive, and hydraulic actuator for gap control.
The focus of this paper was on set up optimization, which happened to be in level 2. It looked for following objectives.

1. Lowest strip thickness variation
2. Unchanged strip profile.
3. Maximum strip rolling speed.

Set –up initialization: Beta factor theory , proposed by R.M.Guo was used to ensure that reduction in
each rolling stand was inside upper and lower reduction limit. Nelder and Mean simplex method was utilized for optimization of variables.
Objective function and constraints:.

1. Maximum set up speed is to be considered for maximum production.
2. Applied force should be smoothly distributed in al stands. But, last stand force is to be regulated, considering roughness and flatness of finished coil.
3. Total set up power is the maintained below nominal power of the mill.
4. Tension between strands should not be more than one third of yield point of sheet.

Conclusion: After carrying out many experiments, the co-efficient and exponents were adjusted. Experimental result shows that revised set up leads to better quality and productivity.

3.5 Minimisation of Thickness Variation & Shape Control in 6 High Rolling Mill Stand

Xiawei Feng, Pierre Montitonnet, Quan Yang, Anrui Hea, Xiaochen Wanga ,et al. (12) had proposed 3D mathematical model for a 6 high Tandem cold rolling mill, provided with intermediate roll shifting facility. Crown provided at working roll was a first order correction to bending of rolls and its flattening. Tandem Mill was provided with work roll and intermediate roll shifting facility. This facility permitted to take faster adaption to minimize gauge thickness variation. Hence, it called for modeling to meet the challenge.
Approach to modeling was as follows. Initially slab model was introduced under plain strain condition. Then an elasto- plastic model was used. Then authors followed 3D semi-analytical elastic roll deformation model based upon roll bending, Timoshenko's beam theory, and roll flattening based upon Boussienesq's equation for a semi-infinite solid. Hertz contact theory was also taken into consideration.
All equations were discredited by 3D influence function method. Resulting non –linear equation were solved by Newton-Raphson schedule. While comparing slab method and FEM method, it was observed that slab method took a few seconds, whereas FEM took considerable minutes.

4. Conclusion

The present market is looking for quality improvement in the product. Cold rolled sheets are mostly used for making automobile body, industrial application , Product quality depends much in uniform quality characteristic input cold rolled sheets, particularly with respect to uniform gauge, uniform shape. So steel manufacturers are looking ahead to meet the challenge of the market etc. It calls for extensive computer modeling with 3D facility. High investment with respect to online measurement of various parameters, computer with high processing speed, and high memory facility, are required to meet the challenge.

Future Work

It will focus on on-line adaption capability due to changes of mill conditions, such as threading, tailing out, passing of a weld(joining of two HR coil a the inlet side) through roll, variation of parameters such as hardness, waviness in input coil, non-uniform lateral flow of material in width direction. Contact mechanism, on-line measurement system may be developed at entry section, also during rolling, and after rolling. Developing 3D FEM method for incorporating all such parameters, and finally validation with measurement are required.

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