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A Calculation Procedure and Optimization for Pass Scheduling in Rolling Process: A Review

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Abstract—*This paper provides an overview of Pass scheduling and its calculation procedure for rolling forces and bending forces. Rolling is a process of reducing thickness of work piece by a compressive force. The force is applied through set of rolls. In each pass after strip thickness rolling parameters for per pass are calculated as tension, rolling speed, rolling time etc.. Pass schedule is reasonable plays a key role to energy consumption, the product quality and equipment efficiency of rolling mill. Rolling schedule affects the shape accuracy and structure properties of finished strips. By considering equal load of rolling power and good shape as main objective function and optimization mathematical models are established. Optimized rolling schedule can improve rolling work status and make sure that strip crown and flatness to be good. At the same time bending force also improves the shape control. Various crown and shape control technologies are also introduced in this paper.*

Keywords*: Bending Force, Crown, Flatness, Optimization, Pass scheduling, Rolling Force, , Shape.*

Introduction

Pass scheduling is a vital factor in steel rolling. Rolling and Bending force's value can be calculated with respect to material parameter such as thickness, width, steel grade, diameter of roll and rolling load limitation condition. Due to roll mill and production development advancement manufacturer enterprises must improve quality and shape accuracy to meet the needs and to achieve market competition. Investigators have developed many optimization model for pass scheduling. The optimization of load distribution is introduced in Ref [1]. Method of energy saving, holding temperature and thickness for pass scheduling calculation of two phases controlled rolling on plate mill is also presented [2].

For most rolling mills bending force is primary factor for shape control. Rolling pass schedule can not only fulfill the requirement of strip crown and flatness but also enhance the setting value of bending force and leave more space for a line control [8]. In this paper we have derived suitable rolling force formula and setting value for bending force for obtaining good strip shape. Equal load of rolling power and good shape as objective function is taken in account.

Profile setup model is the core for shape control in strip [4]. For improving the control quality of profile various study on coupling deformation of roller and strip roller thermal expansion and wear model etc. are made and verified. Crown allocation is considered based on relationship between adjacent stands. The calculation termination conditions before outputting each stand crown are determined by model setting.

Cylindrical coordinate velocity field and respected strain rate are used for upper bound analysis of cold rolling process [4] . For high calculation procedure speed and stability procedure can meet the requirement of online control [3]. Various parameters were compared by dynamic model coupling vertical vibration with horizontal vibration. Coupling roll gap and hydraulic servo type rolling process models were proposed for analysis of rolling parameters [5]. Various methods have been studied for tandem cold rolling production line [7]. Productivity is enhanced. Quality and flatness of product are improved.

Calculation formula of various most suitable efficient rolling process terms:

The important parameter of pass scheduling in rolling is rolling force and bending force. Various strategies are adopted for each stand for shape control.

Let output crown be Δh_b of last stand is affected by rolling force P , bending force $2S_1$, work roll crown ΔD_1 , backup roll crown ΔD_2 and inlet crown ΔH_b .

Let the out let flatness is good and non uniform distribution of longitudinal internal stress can be ignored . Various formulas are given below :

Outlet crown $\Delta H_b = P/K_P - 2S_1/ K_{s1} - \Delta D_1/ K_1 - \Delta D_2/ K_2 - \Delta H_b/ K_0$

Rolling Force $P = K_P[\Delta h_b + 2S_1/ K_{s1} + \Delta D_1/ K_1 + \Delta D_2/ K_2 - \Delta H_b/ K_0]$

Work roll crown $\Delta D_1 = \Delta D_{w1} + \Delta D_{rl} + \Delta D_{ml}$ (Where ΔD_{wl} is crown of original roll profile; ΔD_{rl} is thermal crown; and ΔD_{ml} is wear crown.)

Inlet crown $\Delta H_b = [\Delta h_b/h_n + u'(0) - u'[b/2]] * H_n$ (Where H_n is inlet thickness; h_n is outlet thickness; b is the width of strip; and u(x) is lateral displacement and it can be solved by variational method.)

Setting value modification of bending force $2S_1 = K_{s1} [P/ K_P - \Delta D_1/ K_1 - \Delta D_2/ K_2 + \Delta H_b/ K_0 - \Delta h_b]$

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S#	AUTHOR	PROCESS	OUT PUT	BENIFIT/ CONCLUSION
1	QI Xiang-dong, Wang Tao,XIAO Hong August 24,2011	• Calculation Formula of rolling force is deduced. • Setting method of bending force is studied. • Comparison of rolling power before and after optimization • Comparison of bending force before and after optimization	•Obtaining of good strip shape. •Optimized model of Finish rolling schedule is established.	• Considering strip shape influenced by rolling pass schedule formula of most rolling force is deduced. • Setting method of bending force is researched. • Optimized rolling schedule model is established.
2	Zhu Yu , Cheng Xianmin and Wang Tao 2016	• Computing of Rolling temperature • Computation method of rolling force • Construction of roll schedule optimized model • Example computation and analysis	•Before optimization value of exit thickness /mm , screw down ratio/% •After optimization value of exit thickness /mm , screw down ratio/% •Flow diagram of optimizing •Rolling force and rolling power of before and after optimization comparison	
3	BAI Jan-lan, WANG Jun-sheng 2011-05-12	• A calculation method is used for single stand reversing cold rolling mill. • Newton-Rapshon technique is used for solving non linear equation formed by equal power rolling strategy. • Production quality and output of rolling mill as main objective equal power rolling strategies used for calculating pass schedule.	•Pass schedule is a key role to energy consumption. • Rolling strategies mean which load way to choose to calculate steel thickness of each pass. •Equal power strategy •Equal rolling force strategy •Rolling force mathematics model •Development of pass schedule calculation procedure and flow chart	• The maximum difference between calculated value and actual data of rolling force and power without adaptive learning are less than 8%. • Speed and stability of procedure fulfill the requirement of online process control. • Calculation result is close to actual data. • Procedure is best suitable for single stand cold rolling process.
4	W.Peng. J.G. Ding, D.H. Zhang, D.W.Zhao 4 April 2017	• Rolling force prediction in cold rolled is based on plastic mechanics. • Metal flow in deformation zone was analyzed by cylindrical velocity field. • Internal plastic power, frictional power, shear power, and tense power are minimized. • Upper bound method was used for analysis of metal deformation process.	•Analytical model of rolling force was derived by Bland-Ford. •A solution of Karman's differential equation was found. •FEM model, Viscoplastic model, Elastic plastic models etc. are established for investigation of rolling process. •BP method, Bayesian method, RBF method, Adaptive neural method and predictive network are developed for prediction of cold rolling force.	• Analysis solution of rolling force and stress state coefficient are obtained. • Prediction precision model was a high level means calculation speed and accuracy can fulfill the requirement of process control system of cold rolling.

5	Shao Yimin, Rao Meng, Yang Qihui, Yillin Yuan August 21-24,2016	• Relationship between variation of rolling parameter and vibration characteristics of twenty high rolling mills are studied. • Adjustment strategy for rolling parameter is required for improving the quality of strip surfaces. • Coupling the vertical and horizontal vibration dynamic model is proposed for twenty high rolling mills. • Effects of rolling force, rolling speed, and fluctuation of tension on vibration are studied. • By studying the coupling characteristics Wang proposed a function between vertical vibration and horizontal vibration . • Coupling roll gap and hydraulic servo model was proposed for analysis of rolling parameter. • Distributed model of rolling was proposed for analysis of roll gap shape • Bearing defects on vibration characteristics were analyzed by vertical vibration model.	•On the basis of model effect of rolling force, rolling speed, and fluctuation of tension on vibration of twenty high rolling mills are studied. •Formulation and validation of coupling dynamic model of twenty high rolling mills are obtained.	• Effect of rolling parameter has been studied. • On the fluctuation of rolling speed the amplitude of working rolls fluctuates. It shows linear dependence on fluctuation of tension. • By predicting the adjustment model of rolling parameter resonances are avoided. • Dynamic models of coupling mechanism and vibrations are studied for rolling parameter which affects the surface quality of strip.
6	Arif Malik, JohnSanders , Ramana Grandhi,Mark Zipf , November11-17,2011	• Reliability based optimal cluster mill pass scheduling is used to process flat metals. • Computer control process determine gauge reduction schedule leading to minimum number of passes. • Roll stack deflection model using mixed finite element technique enabled more efficient roll-stack deflection. • By using first reliability method pass scheduling optimization work is extended. • Optimization enables of achieving desired shape flatness for given rolling pas schedule. • Review of profile and flatness is studied.	•Innovative rolling technology gives more solution to metal producers for improving quality and productivity. • Static deflection model, Static solution of global system •Pass schedule optimization and strip crown ratio are determined.	• Influence of crown control on force distribution and strip thickness profile for pass 1 of the 20 high mill schedule is discussed. • Pass exit gage was adjusted for achieving crown of 0.30%. • Probabilistic constraints are incorporated into mathematical optimization routines. • Strip crown is the random output parameter used in reliability based optimization constraint. • Optimization model and roll stack deflection modes are combined to improve the mill setup calculation.

7	H.N.Bu , Z.W.Yan , D.H.Zhang and S.Z.Chen , 16 June 2015	• Tandem cold mill is used for setting of rolling schedule. • Main objective is aimed at thin gauge strip and solved by Tabu search algorithm. • For avoiding strip slipping by reduction of friction coefficient tension schedule was corrected according to rolling length of work roll. • 1450 mm 5-stand tandem cold mill is used for optimization. • Adaptive chaotic mutation suffled frog leaping algorithm is used. • For load equalization genetic algorithm is adapted. • BP neural network is used to predict rolling force and multi objective fuzzy method to optimize objective function.	• Deformation resistance model for accumulating work hardening in tandem cold rolling. • Rolling force model **$F=Blc^{0}KKT$** • Power objective function • Tension objective function • Flatness objective function • Constraints condition • Elastic deformation of roll and forward tensile stress is found.	• On the basis of influence method flatness is obtained and rolling schedule optimization model for thin gauge strip is put forward. • Tensile correction is done according to work roll length. • Quality and flatness of product are also improved.
8	HUANG Changquing, DENG Hua , CHEN Jie , HU Xinghua , YANG Shuangcheng 2011	• According to classical rolling theory AA5052 rolling force model of aluminum was investigated. • Radius of elastic flattened roll, stress state coefficient and deformation resistance were evaluated. • MATLAB was used for rolling force prediction.	• Error between calculation and measured value is obtained 5%-7%. • Aluminum has low flow stress, larger thermal diffusion coefficient, and smaller hardness so it is concluded that strip hot rolling process can't be directly applied for aluminum alloy. • Original schedule setting of rolling force had very large error sharp contrast to actual measured.	• For setting high precision on the basis of classical rolling theory three sub models of elastic flatten roll radius model, stress state factor model and material deformation resistance model were used.

CONCLUSION

Rolling process is a process for making sheets and plates. This is produced by mainly reduction of thickness. Having thickness less than 6 mm is known as sheets and greater than 6 mm is known as plates.

Strip shape is mainly affected by rolling schedule. Suitable formula of rolling force and setting method of bending force is discussed in above papers. Considering relatively equal rolling load power and good shape as main objective function optimization rolling schedule model is established. After optimization it improves the rolling power distribution and strip crown on basis of good shape flatness. Setting method of bending force leaves more space for online shape control. Newton-Rapshon is used for solving non linear equation. Based on equal power rolling strategy pass schedule calculation procedure is developed. Both output and product quality of mill are obtained by suitable procedure. Cylindrical coordinate velocity field and respected strain rate field are discussed upon upper bound analysis and suitable solution of rolling force and stress state coefficient are obtained. Calculation speed and accuracy can meet the requirement of process control. Various models are discussed for obtaining suitable calculation procedure and optimization of rolling force and setting method of bending force. Coupling of horizontal and vertical vibration, dynamic model for deflection, FEM model and viscoplastic model etc. are discussed. So formulation of rolling force and setting method of bending force is main factor which affect the strip flatness and strip crown. By using suitable calculation procedure good shape can be obtained.

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