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An On-Line Portal for Prediction of Roll Force During Hot Strip Rolling Process

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Abstract: An on-line web portal has been developed for prediction of roll force during rolling of steel at Hot Strip Mill (HSM), Rourkela Steel Plant. The prediction of roll force is being done using mathematical-regression hybrid model developed for the purpose. This model is used to calculate roll force during rolling of Cold Rolled Non-Oriented (CRNO) grade of steel. Prediction of roll force is considered highly difficult for this particular grade of steel compared to other carbon-manganese grades. The model has been validated with measured data of 2409 coils of CRNO grade of steel before uploading into the portal. The validation results have been found to be very accurate. The model software reads on-line input data signals from Programmable Logic Controller (PLC) based system and predicts roll force. The software is developed using ASP.Net environment with VB.Net computer language. This paper describes the detailed methodology of model and its on-line implementation in industrial environment.
Keywords: Hybrid Model, Mathematical Model, Regression, On-line porta, CRNO grade of steel

1. INTRODUCTION

Prediction of roll force before entry of material into rolling stands is considered highly difficult for cold Rolled Non-Oriented (CRNO) grade of steel compared to other carbon-manganese grades. Flow stress of steel grade is one of the most important material properties required for mathematical models for prediction of roll force. Flow Stress characteristics of CRNO grade steel is different from other grades of steel. The effect of carbon and silicon on the flow stress of silicon steel was investigated by Serajzadeh and Taheri [1]. They measured flows stress values of silicon steel at a low strain rate range ranging from 0.01 to 1.5 sec^{-1}. The flow stress range was found to be in the range of 50-120 MPa at temperature 1000 ^{0}C. Sengupta et al. [2] performed comprehensive experiments in Gleeble-3500 to determine the flow stress of CRNO steel at strain rate of 10 and 100 sec^{-1} at temperature range 850-1050 ^{o}C. Flow stress range was in the range of 90-175 MPa in case of strain rate at 10 sec^{-1} and 200-275 MPa in the range in case of strain rate of 100 sec^{-1}. Calvillo et al. [3] measured flow stress values of low Carbon (0.003%) and high Silicon (2%) CRNO steel in the temperature range of 800-1100 ^{o}C and strain rate range of 0.01-2 sec^{-1}. The flow stress values changes from 20-85 MPa in this ranges of temperature and strain rate. Zhou and Liu [4] also determined flow stress of silicon steel at strain rate 0.1, 1.0 and 8 sec^{-1} at temperature range 950-1200 ^{o}C. The flows tress values changes from 30-180 MPa in this range. Fischer and Schneider [5] described in detail the influence of deformation process on the improvement of non-oriented electrical steel. Hunady et al. [6] described a general equation for combining the effect of various chemical compositions on Silicon equivalent as:

$$Si_{eq} = [\%Si] + 2[\%Al] - 0.5[\%Mn] + 2.92[\%P] \quad ... (1)$$

where, [%Si], [%Al], [%Mn] and [%P] are percentage of Si, Al, Mn and P in steel composition respectively.

An Artificial Neural Network (ANN) model for flow stress was developed by Tang and Zhou [7]. They used back-propagation algorithm in ANN to co-relate flow stress with strain, strain rate and temperature. Son et al. [8] developed an on-line learning neural network for both long-term learning and short-term learning in order to improve the prediction of rolling force in hot-rolling mill.

Lee and Lee [9] developed a corrective neural-network is trained to predict the rolling force for the first coil and the conventional learning output is used for the remaining coils of the lot. By doing so, the thickness error at the head-end part of the strip is considerably reduced. Moussaoui et al [10] developed a roll force based on ANN where flow stress is also considered as one of the inputs to the network. The model has been found to be very accurate.

Significant information of flow stress characteristics of CRNO grade of steel has been obtained from the literature described above. These data were incorporated in the mathematical for prediction of deformation behaviour of CRNO during hot strip rolling at finishing stands.

This paper describes the methodology of development of a mathematical-regression hybrid roll force model based on-line portal for prediction of roll force of finishing stands of hot strip mill during rolling of CRNO grade of steel. The model has been installed at finishing stands of Hot Strip Mill, Rourkela Steel Plant, India after integrating it with PLC-based Level-1 automation system. This portal receives on-line data from a Siemens-S7416 CPU based

Automatic Gauge Control (AGC) PLC system and a ABB-800PEC based Speed Control PLC system to a MS Access database through an OPC-based data communication software developed for the purpose. The system has also been connected to the VAX based process planning system for receiving primary data input which includes slab dimension, target strip dimension, furnace charging sequence and tracking information. After establishing and testing all the communication, the system has been successfully tried for its on-line operation in the mill during rolling of CRNO grade of steel.

2. METHODOLOGY OF DEVELOPMENT OF HYBRID MODEL

2.1 Mathematical Model

Figure-1 shows a typical rolling process. At the entry of the strip to roll bite, linear speed of roll is higher than the speed of strip and at the exit, linear speed of strip is higher than that of roll. So, there is a point inside where both the speeds are equal and called neutral point. The angle of neutral point with roll centre line is called neutral angle (γ).

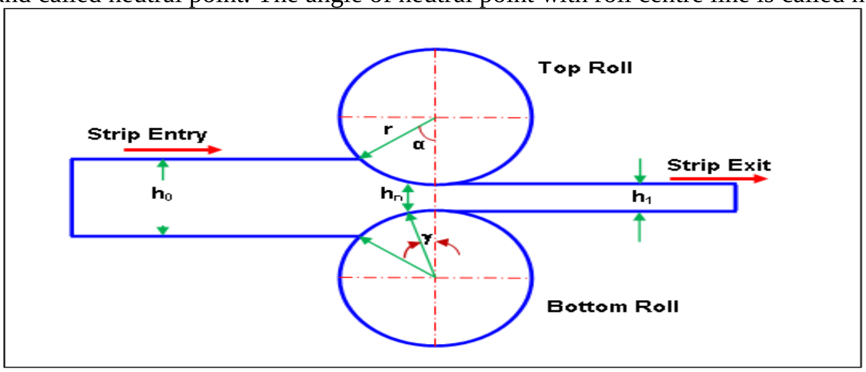


Fig.1: Schematic diagram of Rolling Process

Steps for calculation of roll force using Tselikov's theory is described below:

Model Input

Symbol		**Description**
h_0	:	Entry thickness of Strip (mm)
h_1	:	Exit thickness of Strip (mm)
b_0	:	Width of plate/strip (mm)
R	:	Roll Radius (mm)
v_r	:	Linear Speed of Roll (m/s)
t	:	Rolling Temperature (0C)
E	:	Young's modulus of roll(MPa)
ν	:	Poisson ratio of roll

Model Calculation Steps for Roll Force:

1. Draft (mm), $\Delta h = h_0 - h_1$
2. Projected length of roll arc (mm), $l_p = \sqrt{R\Delta h}$
3. Initial Thickness at neutral section (mm), $h_{n0} = \sqrt{h_0 h_1}$
4. Neutral Angle (Radian), $\gamma = \left(\dfrac{h_{n0}}{h_1} - 1\right)\dfrac{h_1}{l_p}$
5. Forward Slip, $S' = \dfrac{R\gamma^2}{h_1}$
6. Exit Speed (m/s), $v_1 = v_r(1 + S')$
7. Strain Rate (s^{-1}), $\dot{\varepsilon} = \dfrac{1000 v_1 \Delta h}{l_p h_0}$

8. Strain, $\varepsilon = \dfrac{h_0 - h_1}{h_0}$

9. Flow Stress of Material (MPa), $\sigma = \sigma_o \varepsilon^a \dot{\varepsilon}^b e^{-ct}$

10. Yield Stress Plane Strain Compression, (MPa) $k = 1.15\sigma_f$

11. Coefficient of friction, $\mu = 0.55 - 0.00024t$

12. Friction Factor , $\delta = \mu \dfrac{2l_p}{\Delta h}$

13. Thickness at neutral section (mm) $h_n = \left(h_0^{\delta-1} h_1^{\delta+1}\right)^{\frac{1}{2\delta}}$

14. Average pressure at Roll Bite (MPa)

$$p_{cp} = \frac{k}{\Delta h}\left[\frac{h_0}{\delta - 2}\left\{\left(\frac{h_0}{h_n}\right)^{\delta-2} - 1\right\} + \frac{h_1}{\delta + 2}\left\{\left(\frac{h_n}{h_1}\right)^{\delta+2} - 1\right\}\right]$$

15. Width Factor $c_b = 4(1-\varepsilon)(\dfrac{b_0}{l_b} - 0.15)e^{1.5\left(0.15 - \frac{b_0}{l_b}\right)} + \varepsilon$

16. Width increment (mm) $\Delta b = 0.54 c_b \left(l_b - \dfrac{\Delta h}{2\mu}\right)\ln\left(\dfrac{h_0}{h_1}\right)$

17. Average Width (mm) $b_{cp} = b_0 + \dfrac{\Delta b}{2}$

18. Roll Force (MN) $P = p_{cp}\left(\dfrac{b_{cp}}{1000}\right)\left(\dfrac{l_p}{1000}\right)$

19. Elastic zone increment (mm), $x_2 = \dfrac{8\left(1-\nu^2\right)}{\pi E} R p_{cp}$

20. Modified Projection of contact, $l_p^{'} = \sqrt{R\Delta h + x_2^2} + x_2$

21. Repeat Steps 4 to 20 with modified h_n and$l_p$till ε is low.

2.2 Hybrid Model

The concept of hybrid model is shown in Figure-2. This figure shows that the input parameters are used to predict roll force using mathematical model described in the previous section. The Roll force predicted by Tselkov's theory is one of the inputs to the regression model. The other inputs to the model are Carbon %, Silicon Equivalent as described in Equation 1, Temperature, Speed, Roll Gap and Roll Diameter. The regression model is trained using least square error methodology. After training of the model with both input and output data, the regression coefficients are stored in database for further prediction of roll force.

Figure-3 shows the hardware arrangement for integrating the hybrid mill setup model with mill automation system. It consists of a Windows based process work station (PWS) in which the hybrid model is loaded and works on continuous basis. An Operator Work Station (OWS) has also been installed at the operator pulpit in which web-based portal has been installed for operator interface. This level-2 automation system receives on-line data from a Siemens-S7416 CPU based Automatic Gauge Control (AGC) PLC system and a ABB-800PEC based Speed Control PLC system to a MS Access database through an OPC-based data communication software developed for the purpose. Through this system the input data like roll gap settings, entry temperature, roll diameter, rolling speed settings comes to the PWS. Other input data such as diameter of work rolls, chemical composition of steel and size of strips also comes to the PWS from a VAX system. In PWS, all these input parameters are stored in a MS Access database. The model software reads all these input data from the database and calculates speed and draft schedules. The output data passes through the PLC system in similar fashion and the mill is set automatically.

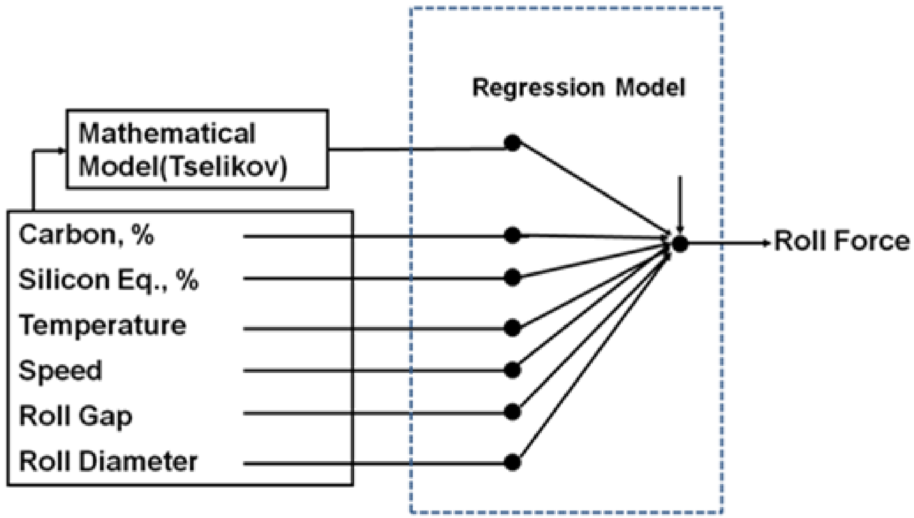


Fig. 2 – Schematic representation of Mathematical-Regression hybrid roll force

2.3 Integration of Hybrid Model with Mill Automation system

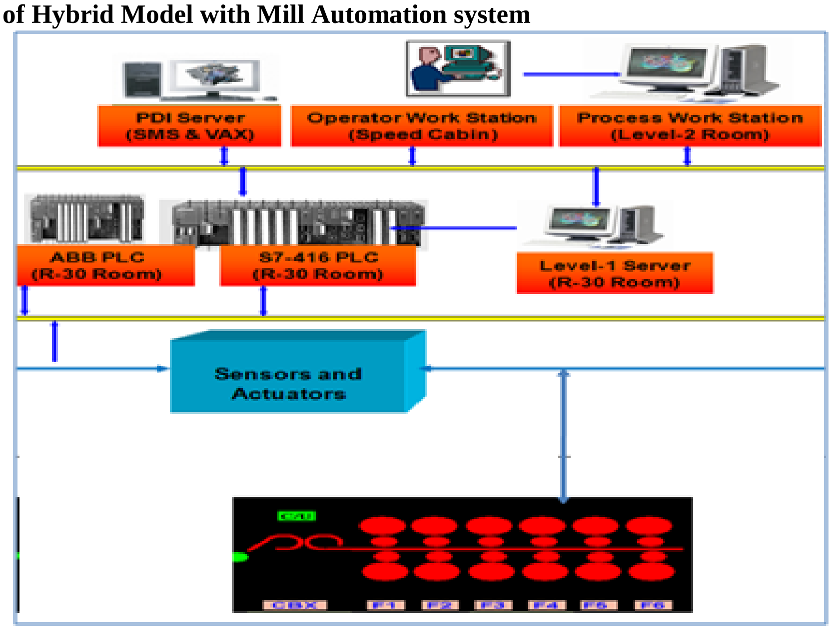


Fig. 3 - Hardware arrangement for implementation of hybrid mill setup model

Figure-3 shows the hardware arrangement for integrating the hybrid roll force model with mill automation system. It consists of a Windows based process work station (PWS) in which the hybrid model is loaded and works on continuous basis. An Operator Work Station (OWS) has also been installed at the operator pulpit in which web-based portal has been installed for operator interface. This level-2 automation system receives on-line data from a Siemens-S7416 CPU based Automatic Gauge Control (AGC) PLC system and a ABB-800PEC based Speed Control PLC system to a MS Access database through an OPC-based data communication software developed for the purpose. Through this system the input data like roll gap settings, entry temperature, roll diameter, rolling speed settings comes to the PWS. Other input data such as diameter of work rolls, chemical composition of steel and size of strips also comes to the PWS from a VAX system. In PWS, all these input parameters are stored in a MS Access database. The model software reads all these input data from the database and calculates roll force.

3. MODEL VALIDATION

Figure-4 shows validation of model predicted roll force with actual measured roll force for 2409 coil samples. It has been found that there is a close matching between the prediction and measured values with Root Mean Square Error (RMSE) of 2.1 MN only showing that the hybrid model prediction as highly accurate.

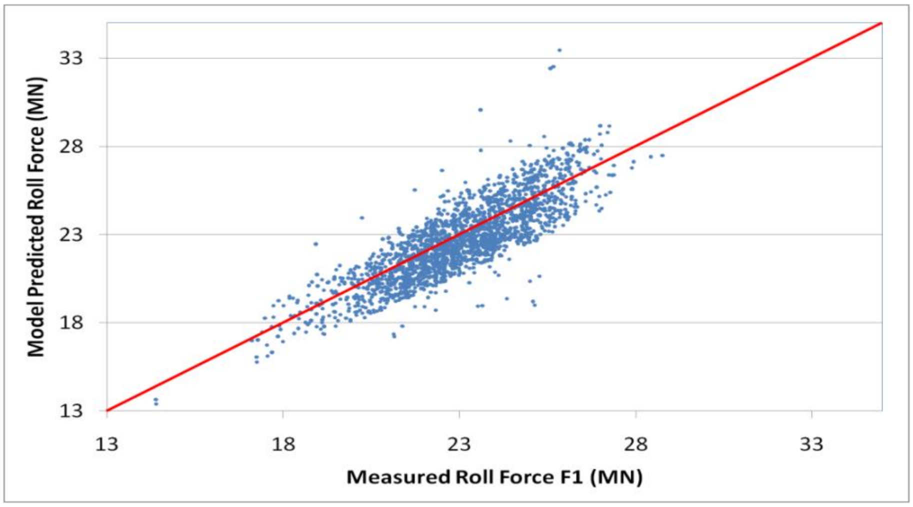
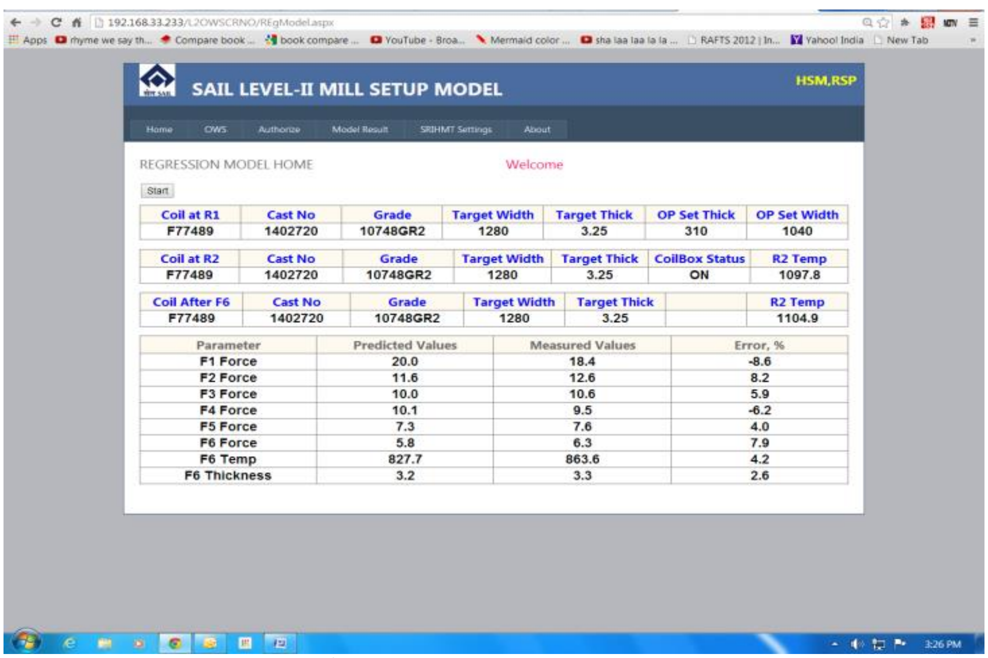


Fig. 4 - Validation of Model Predicted Roll Force with Measured Roll Force

4. MODEL IMPLEMANTATION THROUGH PORTAL

Figure-5 shows screenshot of portal model implemented at HSM, RSP. The model takes all inputs like Grade, Chemical Composition, Width, and Temperature from the automation system and predicts roll force for different stands. The software has been developed using ASP.Net environment with VB.Net computer programming language.



Coil at R1	Cast No	Grade	Target Width	Target Thick	OP Set Thick	OP Set Width
F77489	1402720	10748GR2	1280	3.25	310	1040

Coil at R2	Cast No	Grade	Target Width	Target Thick	CoilBox Status	R2 Temp
F77489	1402720	10748GR2	1280	3.25	ON	1097.8

Coil After F6	Cast No	Grade	Target Width	Target Thick		R2 Temp
F77489	1402720	10748GR2	1280	3.25		1104.9

Parameter	Predicted Values	Measured Values	Error, %
F1 Force	20.0	18.4	-8.6
F2 Force	11.6	12.6	8.2
F3 Force	10.0	10.6	5.9
F4 Force	10.1	9.5	-6.2
F5 Force	7.3	7.6	4.0
F6 Force	5.8	6.3	7.9
F6 Temp	827.7	863.6	4.2
F6 Thickness	3.2	3.3	2.6

Fig. 5: Screenshot of portal in operation at Hot Strip Mill, Rourkela Steel Plant

5. CONCLUSIONS

- Flow stress of CRNO grade of steel is an important parameter because the material changes its phase from austenite to ferrite during deformation in the mill for this grade whereas the phase change takes place during post-deformation laminar cooling for most of the other grades of steel

- A Mathematical-Regression hybrid model has been developed for prediction of roll force during Hot Strip Rolling.
- The model has been validated with measured data and found to be accurate.
- The model has been implemented in industry (HSM, RSP) with a web-portal developed for the purpose.

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