Abstract

Title: SYSTEM AND METHOD FOR FACILITATING AUTOMATIC HOT ROLLING OF COLD ROLLED NON-ORIENTED (CRNO) GRADE STEEL STRIPS IN A HOT ROLLING MILL

A system and a method provided for facilitating hot strip rolling of steel including Cold Rolled Non Oriented (CNRO) grade steel in hot strip rolling mill. The present system and method is adapted to automatically and efficiently calculate draft and speed schedule for hot rolling of CNRO grade steel in the hot strip rolling mill in accordance with flow stress characteristics of the steel. The system and the method automatically and correctly determine the mill calibration parameters like roll force, torque, power, finishing stand temperature before entry of the steel to the stands and drive the rolling operation without slowing the speed and without increasing the roll gap values.

Figure 4

We claim:

1. A system for facilitating automatic rolling or coiling of steel strips in a hot rolling mill comprising

   PLC system for acquiring process data of the rolling including roll gap, entry temperature of the steel strips, roll diameter, rolling speed;

   VAX system for acquiring primary data including diameter of work rolls, chemical components of the steel and size of the strips;

   process works station operatively connected with the PLC system and the VAX system for receiving the process data and the primary data and executing a hybrid mill set-up model by involving the process and the primary data and thereby predicting draft and speed schedule for rolling;

   said draft and speed schedule is operatively transmitted to the rolling mill hardware through the PLC system for said automatic rolling or coiling of steel strips in a hot rolling mill in accordance with the generated schedule.

2. The system as claimed in claim 1, wherein the said process work station comprises an operator work station providing an interface to the operator for displaying the draft and speed schedule and allowing the operator to acknowledge the forwarding said draft and speed schedule to the rolling mill hardware.

3. The system a claimed in anyone of the claims 1 or 2, wherein the said process works station comprises MS access database for storing the process and the primary data and providing the same to the hybrid mill set-up model for determining the draft and speed schedule.

4. The system as claimed in anyone of the claims 1 to 3, wherein the said hybrid mill set-up model calculates the strip temperature, roll force, torque and power for determining the draft and speed schedule.

5. The system as claimed in anyone of the claims 1 to 4, wherein the said hybrid mill set-up model involves artificial neural network for calculating the roll force, wherein the said artificial neural network executes prediction of roll force by involving Sims' theory and Tselikov's theory alongwith the PLC system acquired process data and the VAX system acquired primary data as input parameter.

6. The system as claimed in anyone of the claims 1 to 5, provided for automatic scheduling draft and speed during hot strip rolling of CRNO grade steel, the said artificial neural network involving temperature dependent Flow stress as an input parameter for calculating the roll force.

7. The system as claimed in claim 6, the temperature dependent Flow stress variations of the CRNO grade steel are temperature range wise isolated, wherein each of the isolated temperature range provides single state of the Flow stress variation which is anyone of the increment of the Flow stress variation and decrement of the Flow stress variation with respect to the temperature.

8. The system as claimed in anyone of the claims 1 to 8, wherein the said hybrid mill set-up model comprises Auto Adaptation module adapted to acquired data from the PLC system after rolling is completed and trains the artificial network with the measured data of roll force, temperature and predicted final strip thickness for predicting error free mill calibration coefficients.

9. A method for automatically determining draft and speed schedule in hot strip rolling mill during rolling of steel strips involving the system as claimed in anyone of the claim 1 to 8 comprising

   acquiring the primary data from the VAX system and thereby calculating temperature of the CNRO grade steel strip, roll force, torque, power, looper tension and motor current before entry of the CNRO grade steel to different stands of the hot strip rolling mill;

measuring values of roll force, temperature and thickness of strip after the rolling and training the ANN model of the hybrid mill set-up model for minimizing error between the calculated and the measured data and thereby generating the modified values;

predicting optimized mill calibration coefficients by using the modified values for the next coil.

10. The method as claimed in claim 9 for automatically determining draft and speed schedule during hot rolling for CNRO grade steel strips comprising

isolating temperature dependent flow stress variations of the CNRO grade steel in separate temperature ranging zones, wherein each of the temperature ranging zone provides single state of variation i.e. either increment or decrement in the flow stress with respect to the variation in the temperature;

differently determine the calibration coefficients separately for each zone.

Date this the 20th day of January, 2014

Anjan Sen

(Applicants Agent)

(IN/PA 199)

STEEL AUTHORITY OF INDIA

6 SHEETS
SHEET 1

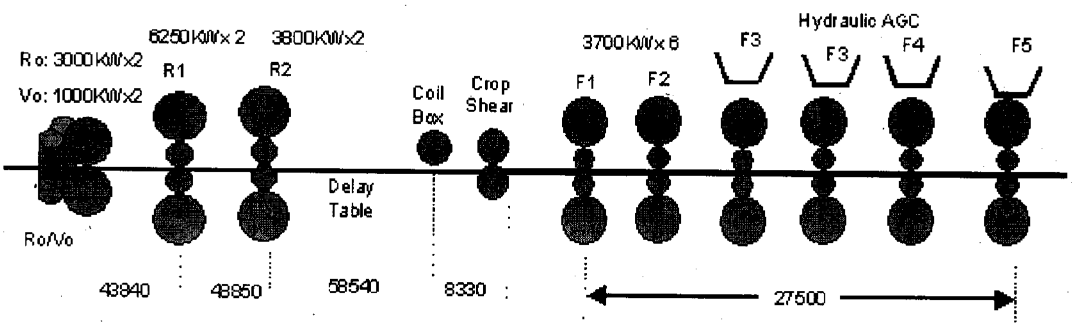

Figure 1

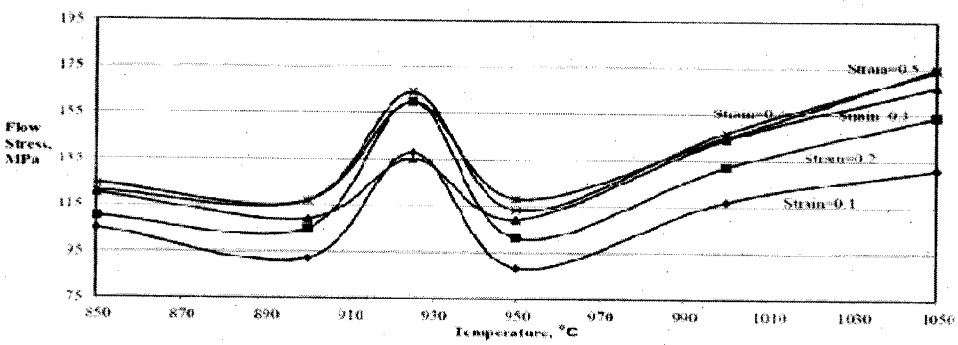

Figure 2

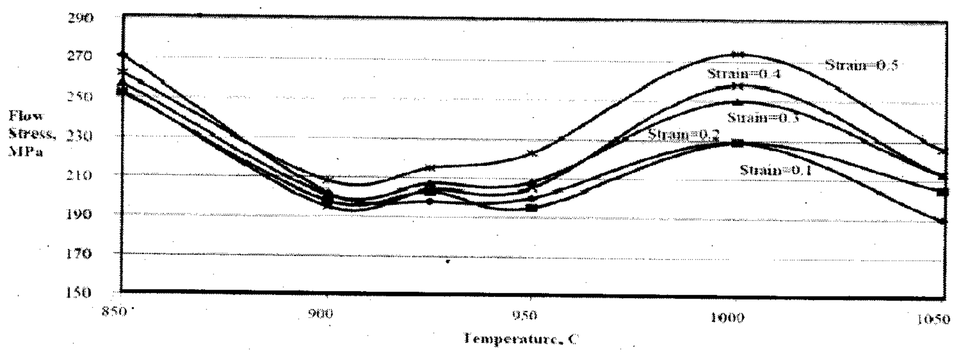

Figure 3

ANJAN SEN
(Applicants Agent of ANJAN SEN & ASSOCIATES)

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SHEET 2

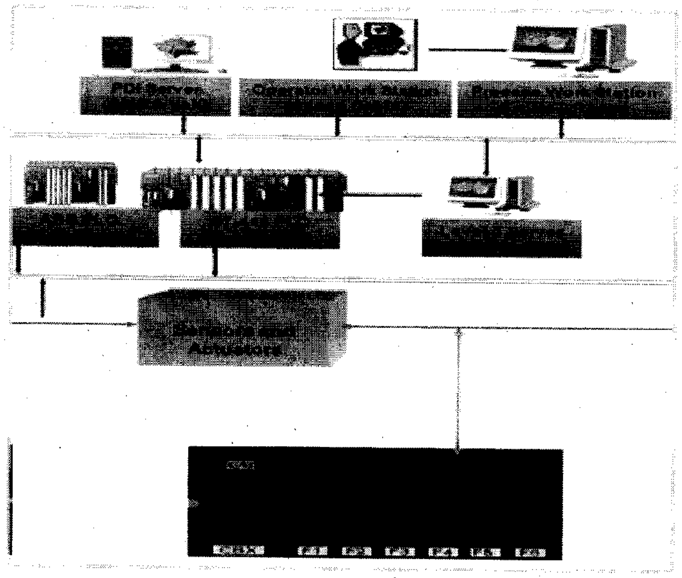

Figure 4

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SHEET 3

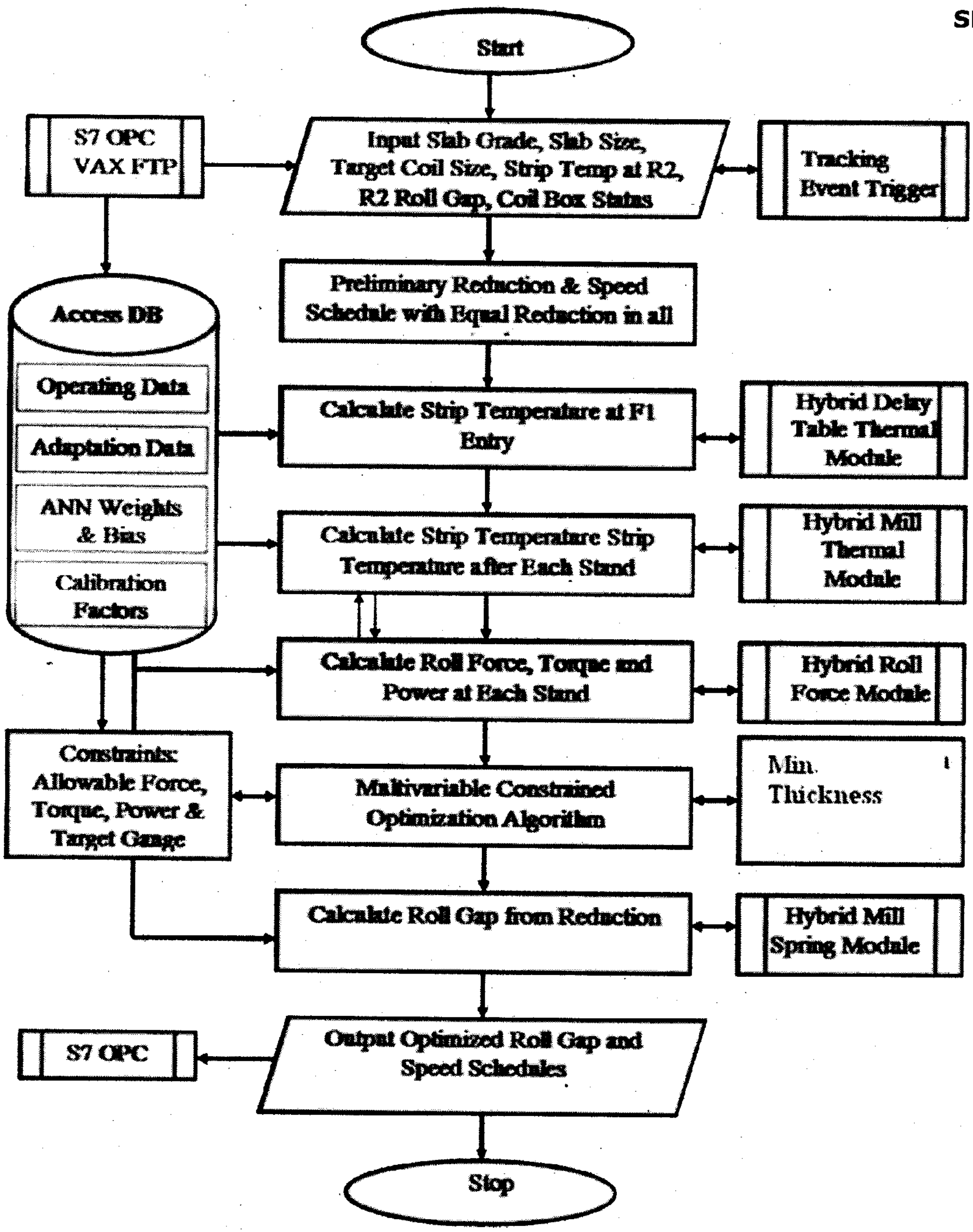

Figure 5

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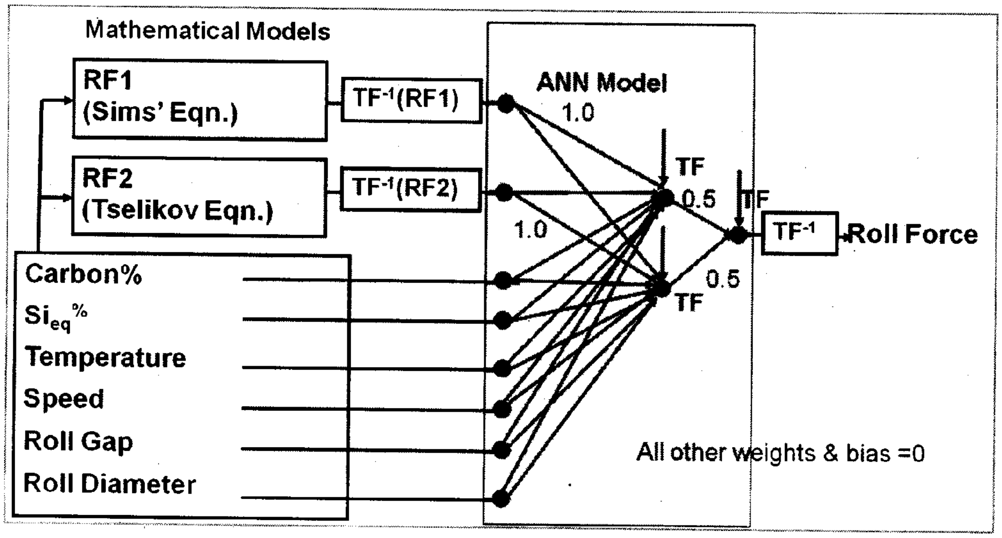

Figure 6

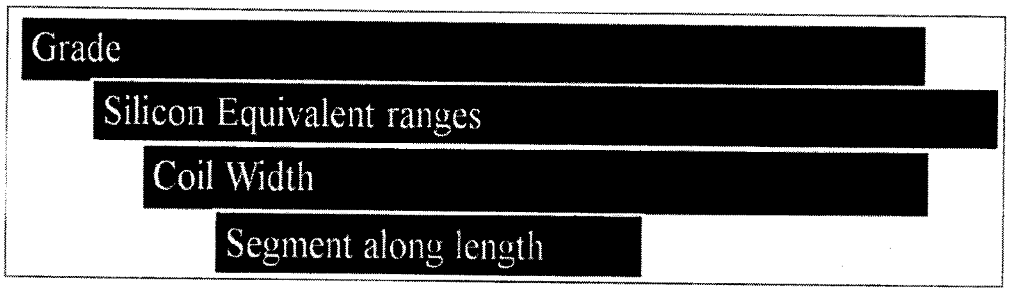

Figure 7

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(Applicants Agent of ANJAN SEN & ASSOCIATES)

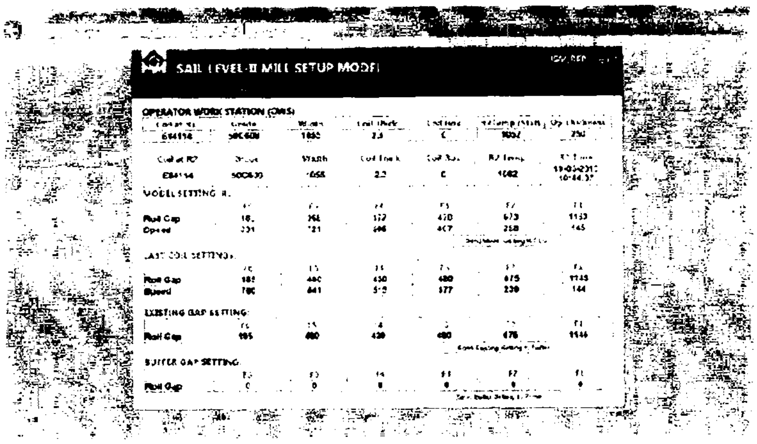

Figure 8

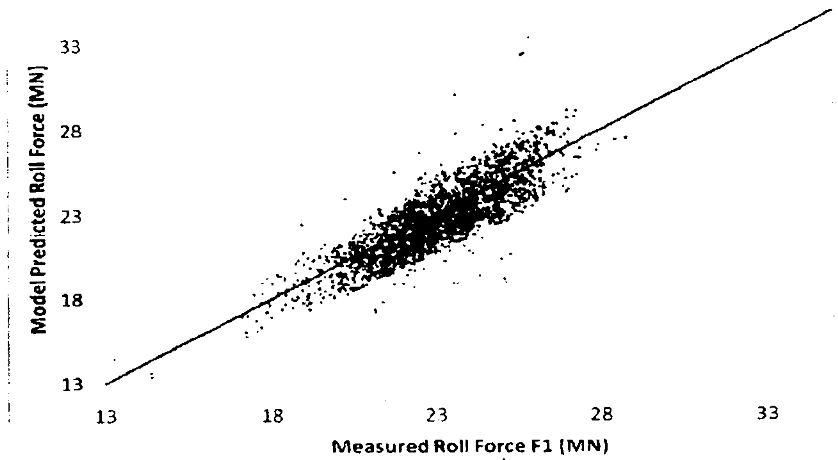

Figure 9

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(Applicants Agent of ANJAN SEN & ASSOCIATES)

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SHEET 6

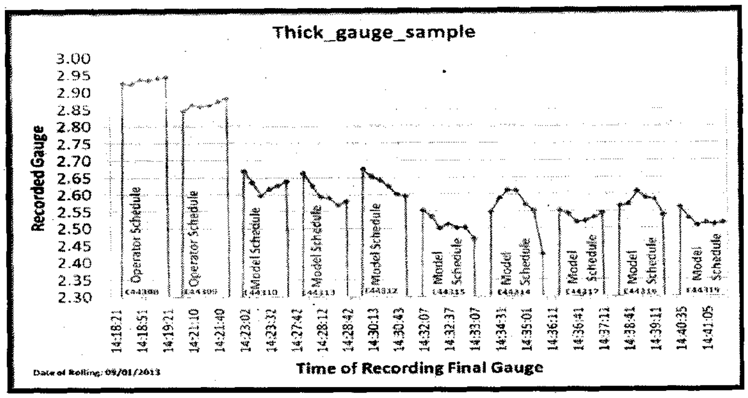

Figure 10

ANJAN SEN
(Applicants Agent of ANJAN SEN & ASSOCIATES)

FIELD OF THE INVENTION:

The present invention relates to facilitate hot strip rolling of Cold Rolled Non Oriented (CNRO) grade steel in hot strip rolling mill. In particular the present invention is directed to develop a hybrid mill set-up model and an integrated mill automation system adapted to automatically and efficiently calculate draft and speed schedule during hot rolling for CNRO grade steel in the hot strip rolling mill. The present invention is particularly useful to facilitate and optimize the operation of hot strip rolling mill.

BACKGROUND OF THE INVENTION:

Strips of different grades, thickness and width are rolled from slab in a hot strip mill. The conventional Hot Strip Mill comprises 3 Roughing stands and 6 Finishing stands. The first roughing stand (R_0/V_0) is a combination horizontal stand and a vertical stand. The other two roughing stands (R_1 and R_2) are 4 high horizontal stands. There is a delay table after R_2 stand, one coil box and a crop shear at the end of the delay table. There are six numbers of 4 high finishing stands (F_1 to F_6) and two hydraulic down coilers. A schematic diagram of such mill is provided in the accompanying figure 1. These mills are manual operated and the draft and speed schedules for different stands are set by the operator. The values of roll gap for draft schedule and the values of speed for speed schedule at different stands are calculated by the operators based on their experience and skill. Often erroneous calculation disturbs the mass balance of material flow between different stands.

Now the rolling of CRNO grade of steel in finishing stands of HSM often creates difficulty to operators. While it is easier for the operators to predict a suitable range of values for the parameters like roll force, torque, power, finishing temperature before entry of the material to stands, it is very difficult to predict these parameters for CRNO grade of steel as the flow stress characteristics of the CRNO grade of steel is completely different from other material. Since parameters are important for draft and speed scheduling and wrong prediction may lead to violation of mill constraints, the mill operators has operate the mill with very caution. They operate the mill with slower speed than desired and roll gap values are often set at higher side than desired. This leads to loss of productivity of mill due to low speed and also high finishing thickness (more than target finishing thickness value of 2.3 mm). Higher finishing thickness leads to increase in number of reversing passes during subsequent cold rolling thereby decreasing cold mill productivity.

Thus there has been always need for a system or method which would be adapted to automatically and correctly determine parameters like roll force, torque, power, finishing temperature before entry of the material to stands, so that hot strip rolling of the CRNO grade of steel can done without slowing the speed and without increasing the roll gap values.

OBJECTS OF THE INVENTION:

It is thus the basic object of the present invention is to develop a model which would be adapted to automatically determine optimize calibration parameters of a hot rolling mill and facilitate the automatic operation of the hot rolling mill based on the said calibration parameter.

Another object of the present invention is to develop a model which would be adapted to adapted to automatically determine optimize calibration parameters a hot rolling mill for hot rolling of CRNO grade of steel.

Yet another object of the present invention is to develop an rolling mil automation system which would be adapted to operated integrate with the model for determining optimize calibration parameters hot rolling mill and accordingly operate different hardware of the rolling mill.

SUMMARY OF THE INVENTION:

Thus according to the basic aspect of the present invention, there is provided a system for facilitating automatic rolling or coiling of steel strips in a hot rolling mill comprising

PLC system for acquiring process data of the rolling including roll gap, entry temperature of the steel strips, roll diameter, rolling speed;

VAX system for acquiring primary data including diameter of work rolls, chemical components of the steel and size of the strips;

process works station operatively connected with the PLC system and the VAX system for receiving the process data and the primary data and executing a hybrid mill set-up model by involving the process and the primary data and thereby predicting draft and speed schedule for rolling;

said draft and speed schedule is operatively transmitted to the rolling mill hardware through the PLC system for said automatic rolling or coiling of steel strips in a hot rolling mill in accordance with the generated schedule.

In the present system for facilitating automatic rolling or coiling of steel strips in a hot rolling mill, the said process work station comprises an operator work station providing an interface to the operator for displaying the draft and speed schedule and allowing the operator to acknowledge the forwarding said draft and speed schedule to the rolling mill hardware. The said process works station comprises MS access database for storing the process and the primary data and providing the same to the hybrid mill set-up model for determining the draft and speed schedule.

According to another aspect in the present system, the said hybrid mill set-up model calculates the strip temperature, roll force, torque and power for determining the draft and speed schedule.

According to yet another aspect in the present system, the said hybrid mill set-up model involves artificial neural network for calculating the roll force, wherein the said artificial neural network executes prediction of roll force by involving Sims' theory and Tselikov's theory alongwith the PLC system acquired process data and the VAX system acquired primary data as input parameter.

According to further aspect in the present system, provided for automatic scheduling draft and speed during hot strip rolling of CRNO grade steel, the said artificial neural network involves temperature dependent Flow stress as an input parameter for calculating the roll force.

According to another aspect in the present system provided for automatic scheduling draft and speed during hot strip rolling of CRNO grade steel, the temperature dependent Flow stress variations of the CRNO grade steel are temperature range wise isolated, wherein each of the isolated temperature range provides single state of the Flow stress variation which is anyone of the increment of the Flow stress variation and decrement of the Flow stress variation with respect to the temperature.

According to yet another aspect in the present system, the said hybrid mill set-up model comprises Auto Adaptation module adapted to acquired data from the PLC system after rolling is completed and trains the artificial network with the measured data of roll force, temperature and predicted final strip thickness for predicting error free mill calibration coefficients.

In accordance with another aspect in the present invention there is provided a method for automatically determining draft and speed schedule in hot strip rolling mill during rolling of steel strips involving the present system comprising

acquiring the primary data from the VAX system and thereby calculating temperature of the CNRO grade steel strip, roll force, torque, power, looper tension and motor current before entry of the CNRO grade steel to different stands of the hot strip rolling mill;

measuring values of roll force, temperature and thickness of strip after the rolling and training the ANN model of the hybrid mill set-up model for minimizing error between the calculated and the measured data and thereby generating the modified values;

predicting optimized mill calibration coefficients by using the modified values for the next coil.

According to another aspect in the said method provided for automatically determining draft and speed schedule during hot rolling for CNRO grade steel strips comprising

isolating temperature dependent flow stress variations of the CNRO grade steel in separate temperature ranging zones, wherein each of the temperature ranging zone provides single state of variation i.e. either increment or decrement in the flow stress with respect to the variation in the temperature;

differently determine the calibration coefficients separately for each zone.

BRIEF DESCRIPTION OF THE ACCOMPANYING FIGURES:

Figure 1 shows a schematic illustration of hardware associated with a conventional hot strip rolling mill.

Figure 2 and 3 shows the flow stress characteristics of CRNO grade of steel obtained from experimentation in dynamic thermo-mechanical simulators (Gleeble-3500) at strain rate of 10 s^{-1} and 100 s^{-1} respectively.

Figure 4 the hardware arrangement of a mill automation system adapted to integrate with hybrid mill setup model in accordance with the present system.

Figure 5 shows the flow chart for the determination of the draft and speed schedule during hot rolling by involving the Hybrid mill set-up model of the present invention.

Figure 6 shows a schematic diagram showing conceptual representation of hybrid roll force module which is an essential component of the present Hybrid mill setup model.

Figure 7 shows the hierarchical data groups used in the AAM of the present Hybrid mill setup model.

Figure 8 shows screenshot of web-portal based hybrid model output installed at the finishing stand of Hot Strip rolling mill.

Figure 9 and 10 shows results of the Industrial trials carried out in the mill with hot rolling of CRNO grade of steel from the newly developed hybrid model based system.

DETAILED DESCRIPTION OF THE INVENTION WITH REFERENCE TO THE ACCOMPANYING FIGURES:

Reference is first invited from the accompanying figure 2 and 3 which shows the flow stress characteristics of CRNO grade of steel obtained from experimentation in dynamic thermo-mechanical simulators (Gleeble-3500) at strain rate of 10 s^{-1} and 100 s^{-1} respectively. As stated earlier the CRNO grade steel shows different flow stress characteristics compare to other material, the same can be verified with the results as shown in the figure 2 and 3. It is a common perception that if a material is heated to higher temperature, the stress required to deform it is lower. So, generally flow stress of material decreases with increase in temperature. However, this is not the case of the CRNO grade of steel. The flow stress characteristic shows that it varies with change in temperature. It is not only temperature dependent, but also strain rate dependent.

Reference is next invited from the accompanying figure 4, which shows the hardware arrangement of the mill automation system for integrating the hybrid mill setup model with existing hot strip rolling mill. The hardware arrangement comprises Windows based process work station (PWS) in which the Hybrid mill setup 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 process work station is connected with two PLC systems using an OPC network. Through this PLC system the input process data like roll gap settings, entry temperature, roll diameter, rolling speed settings comes to the PWS. The hardware arrangement also comprises a VAX system for providing primary data such as diameter of work rolls, chemical composition of steel and size of strips to the PWS. In PWS, all these input parameters are stored in a MS Access database. The hybrid mill setup model application 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 rolling mill is set automatically.

Reference is now invited from the accompanying figure 5, which shows the flow chart for the determination of the draft and speed schedule during hot rolling by involving the present Hybrid mill set-up model. The determination of the draft and speed schedule includes calculation of different deformation parameters like roll force, torque and power before entry of material to finishing stands.

As shown in the said figure the scheduling process starts with acquiring the primary and process data such as Input steel grade i.e. chemical composition of steel, strip temperature at roughing stands of the hot rolling mill, the roll gap, coil box status, target coil size. After acquiring this primary data the speed schedule is equally reduced in all stands. Next the strip temperature at the first high finishing stand is calculated by involving Hybrid delay table thermal module associated with the present Hybrid mill set-up model and then strip temperature after each stand is calculated by involving Hybrid mill thermal module of the said mill set-up model. After this Roll force torque and power at each stand is continuously calculated by using the Hybrid roll force module of the said mill set-up model.

The accompanying figure 6 shows a schematic diagram having conceptual representation of hybrid roll force module which is an essential component of the present mill setup model. Two well known theories i.e., Sims' theory and Tselikov's theory taken from literature have been used in the hybrid model to calculate roll force using mathematical equations. RF1 represents roll force predicted from Sims' theory and RF2 represents roll force predicted from Tselikov's theory. An Artificial Neural Network (ANN) model algorithm selected as feed-forward back propagation algorithm with variable learning rate and conjugate gradient technique of error minimization. These two calculated parameters are considered as inputs to the ANN model along with 6 other input parameters like carbon component in the steel, silicon equivalent, temperature of the steel strip, roll gap, roll diameter which affect roll force as shown in the figure. All the 8 input variables and output roll force have been normalized to values 0 to 1. There is one hidden layer with 2 nodes in the ANN model. The model transfer function has been chosen as tansig function (which is mathematically equivalent to tanh function).

Normalized values of RF1 and RF2 have been functionalized (with a function $\tanh^{-1}$) as shown in the figure. The ANN output has been again functionalized with same $\tanh^{-1}$ function to predict normalized value of roll force. Generally, initial weights & biases are chosen as random numbers during training of ANN models. But, in this hybrid model, the weight between first input node and first hidden node has been chosen as Unity. Similarly, the weight between second input node and second hidden node has also been chosen as Unity. Values of two weights connecting hidden nodes to output node is chosen as 0.5. All other weights and biases of the network have been chosen as zero. The functionalization and initial weight selection have been made in such a way that when input data would be passed to the untrained network, then the predicted roll force would be arithmetic average of roll forces predicted by Sims' theory and that predicted by Tselikov's theory.

In the present scheduling of the draft and speed, a multivariable optimization technique is used to reduce the target thickness and predicts the roll gap and speed for different stands considering all the mill constraints within the specified limits.

The factor Si Equivalent (Si_{eq}) used in the model, obtained from literature, is given by the following equation:

$$Si_{eq} = [\%Si] + 2[\%Al] - 0.5[\%Mn] + 2.92[\%P]$$

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

The hybrid mill set-up model has an Auto Adaptation module (AAM). It takes input data from the system and calculates temperature of strip, roll force, torque, power, looper tension and motor current before entry of material to different stands using Mathematical-Regression-ANN model of the hybrid mill set-up model. The measured values of roll force, temperature and thickness of strip are recorded after the rolling and the ANN model of the hybrid mill set-up model is trained with the measured data. The error between the predicted and measured data are minimized to determine modified values calibration coefficients, weights and bias of the hybrid model using a self-activated multivariable optimization algorithm. The modified values are used for prediction of parameters for the next coil. For this purpose the calibration data has been divided into a hierarchical data groups. The accompanying figure 7 shows the hierarchical data groups used in the AAM. This shows that separate ANN trainings are executed for each group consists of a grade, a Silicon Equivalent, coil width and segment number.

In the present hybrid mill set-up model the typical flow stress characteristics of the CRNO grade steel is also used as the input parameter to the present roll force module for optimizing the rolling procedure. In the present scheduling procedure the temperature dependent flow stress variations are divided into three separate temperature ranging zones, wherein each of the temperature ranging zone provides single state of variation i.e. either increment or decrement in the flow stress with respect to the variation in the temperature. Different flow stress equations have been developed for each of the three zones and the calibration coefficients have been determined separately for each zone.

Figure-8 shows screenshot of web-portal based hybrid model output installed at the finishing stand of Hot Strip rolling mill. When the operator presses "Send Model Setting to PLC", the mill is automatically set with the model predicted Roll Gap (Draft) and Speed Settings.

Industrial Validation of Model

Industrial trials have been carried out in the mill with hot rolling of CRNO grade of steel from the newly developed hybrid model based system and the results of the trials are provided in the accompanying figure 9 and 10.

Figure-9 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 1.2 MN only. Figure 10 shows that there is substantial reduction of finished thickness of CRNO grade coils rolled in hybrid model based system.