STRAIGHTENING OF BARS USING STATISTICAL CONSIDERATIONS

ABSTRACT

Submitted by

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1. Introduction

Most manufacturing industries require straight round bars as input materials for production of various circular products like shafts, links, connecting rods, spindles, pins, tie rods, support rollers, bolts, long screws etc. which comes from rolling mills are often not so round and also not so straight so as to directly employ as final product. In metal-based manufacturing industries, dimensional precision is a prime concern. When round bars are not adequately straight, it actually means that curvatures exist along the length of bars which are not necessarily always uniform along the length but randomly vary at various sections. Long bars produced in rolling mills show that curvatures would exist at various sections along the length of bars in most cases thus often requiring straightening operation. Some industries have grown even for straightening process to enable their output as input materials for production jobs. Beside general purpose manufacturing through various machines, it has been seen that most printing machineries include large number of support rollers to facilitate proper movement of printing substrates using straight round bars in the form of shafts, links etc. for quality printing output. Many standard straightening methods are available in industries and among these, Two cross-roll straightening is quite common and widely used due to its speed of operation for precision and effectiveness. The present investigation is thus focused on two cross-roll straightening.

2. Objective of the present work

Literature review reveals that hardly any research wok concerning statistical aspects in bar straightening process has taken place, hence present research had multiple objectives. The mechanics part was objectively dealt initially as to look into the effect of helix angle in the bar straightening process. The probabilistic approach concerning final residual curvature has been attempted for expected value based probability of final residual curvatures along the bar length.

An objective was application of statistics in bar straightening, developing a theoretical framework by using two-factor, three-factor and four-factor factorial design using ANOVA. The present research was centred on straightness of round

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bars; hence an objective was also to study the circularity or roundness of commercially available bars along with feature of straightness using various statistical tools. FEM is also applied to check the validity of the experimental results obtained by using dial gauge method to observe the deformation behaviour to ascertain its straightness both before and after straightening. Finally, a novel methodology of prediction of metal round bars has been developed using different ML algorithms.

3. Scope of the present work

Present investigations emphasise use of dial gauge, statistical tools as well as finite element method and machine learning algorithms as experimental tools to study straightness of round bars. The experimental technique for this research using dial gauge is quite simple and does not cost much. Moreover, the results obtained from statistical analysis will be helpful for prediction of potential defects in straightness of commercial bars instantly which certainly allow to make informed decisions about process improvement. Finite element analysis of deformations of round bars before and after straightening is quite useful for validation purpose with the results obtained from experimental and statistical analyses. Machine learning algorithm used for predictive modelling of straightness of metal bars will allow proper forecasting of straightness after two cross-roll straightening process which can be implemented in manufacturing process.

4. Research Methodology

Based on the objectives and scope of work, certain methodologies have been considered for analysis. A statistical approach was made with Two-Factor, Three-Factor and Four-Factor Factorial Design on residual curvatures where one factor was helix angle and the other factor was roller diameter. An experimental set up consisting of V-Block on a small structural arrangement with dial gauge mounting was made to measure deformations and observations recorded for various angular positions circumferentially at regular interval of about 15^{o} at small length segments of four different sizes and four different types of materials before and after straightening process. Experimental datasets were analysed using various statistical

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methods and have been validated using FEM. Also, predictive modelling of deformation of straightened bars have been conducted by using different machine learning regression algorithms to obtain accurate forecasting of straightness of metal bars.

5. Discussion on results obtained

The present investigation would be used to determine both qualitative and quantitative information of deformation behaviour of various sizes and types of materials. Statistical analysis reveals that straightness actually improves after the process but more significantly in case of non-ferrous materials. This outcome is quite significant in bar straightening study.

FEA analysis revealed that round bars have considerable deformations at various sections over the length segments and shows that after straightening process, straightness improved more significant in case of aluminium and copper than ferrous materials.

Experimental results have been considered for predictive modelling of straightness by using machine learning. Various algorithms such Linear Regression (LR), Support Vector Regression (SVR), Random Forest Regression (RFR), Extreme Gradient Boosting (XgBoost) and Decision Tree (DT) have been considered for prediction and residual plots. The results are assessed using objective evaluation metrics for regression analysis. Different metrices namely R-squared value (R^2), root mean square error (RMSE), mean absolute error (MAE) and model training time are used for evaluation purpose. It can be seen that RFR remarkably outperformed other regression models in terms of R^2. Predictions are in the tune of 0.92 to 0.99 for Aluminium and Copper round bars in all cases thus conveying about 95-99% accuracy for non-ferrous materials using RFR model whereas for mild steel and stainless steel the accuracy is about 90%. Therefore, the predictive modelling using machine learning models are more effective for non-ferrous materials than ferrous materials.

6. Conclusions and Major Contributions

Major contribution in this research is to work on setting of a criterion on helix angle in two cross-roll straightening machine which can be used scientifically by

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manufacturing industries as what should be the helix angle and its related consequences on the process. Detailing of statistical aspect with ANOVA correlating helix angle and roller diameters is an important theoretical outcome of this research work to get improved straightness.

Two key contributions have been made which could be considered as novelty of this research work. Firstly, deformation analyses of round metal bars of different materials after cross-roll straightening indicate quite improvement as compared to that of results before straightening. Secondly, round metal bars of non-ferrous materials after cross-roll straightening show more significant achievement than that of the ferrous materials.

Another novel significant contribution made in this research is use of Machine Learning. The comparative analysis conducted to explore which machine learning algorithms predicts best straightness. Applying LR, SVR, RFR, XgBoost and DT algorithms on experimental datasets for round bars of all sizes, RFR has ben found as the best regression model. For aluminium and copper bars the prediction accuracy for RFR model has been found about 90-99%, whereas for mild steel and stainless steel the accuracy is about 90%. Therefore, it can be said that effect of cross-roll straightening process is more significant for non-ferrous materials than ferrous materials. Finally, it can be stated that the overall performance of RFR for prediction of straightness in terms of circumferential deformations of metal bars may be considered as promising and potential tool.

7. Graphical Abstract:

The graphical abstract illustrates the visual summary of the research framework for the study of straightening of metal round bars using statistical analysis, finite element analysis and regressive modelling.

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A Graphical Abstract on Straightening of Bars using Statistical Considerations

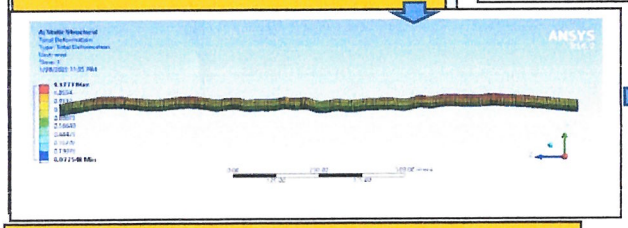
Commercial round bars are seldom straight which needs to be straightened before actual deployment in many industrial applications.

A study has been made to see straightening of bars using STATISTICAL CONSIDERATIONS of commercial round bars through Two Cross-Roll straightening process.

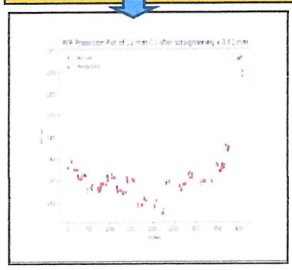
Research Gaps noticed in straightening publications and objectives developed.

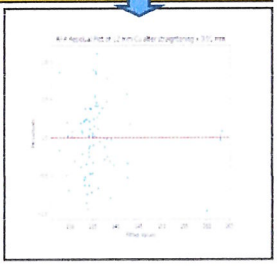
- Probabilistic and Statistical orientation in straightening process.
- Statistical Analysis of deformations before straightening using deflection data

- Theoretical framework by using Two Factor Factorial Design by ANOVA
- Setting criterion for Helix Angle as key parameter for the process
- Analysis of deformations using FEM before and after straightening indicating validation of straightening process.

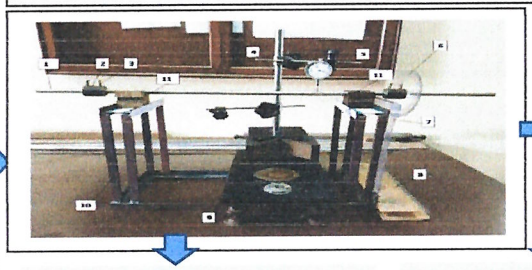


- Prediction Plot and Residual Plot from Straightening Data using machine learning





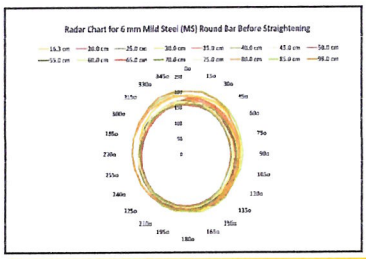
Experimental Set up for Dial Gauge and Measurements



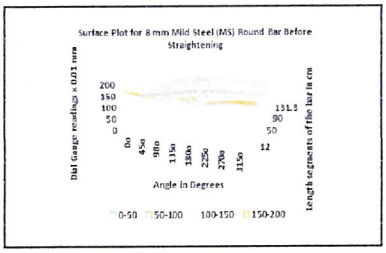
Data from Experiment

- Dial Gauge Deflection reading (x 0.01) mm
- Length segments in cm
- Angles of rotation of round bar in degree

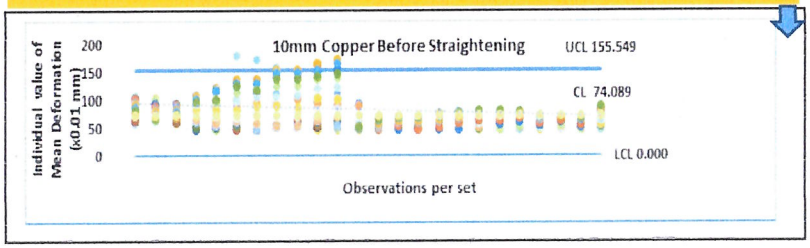
Radar Chart

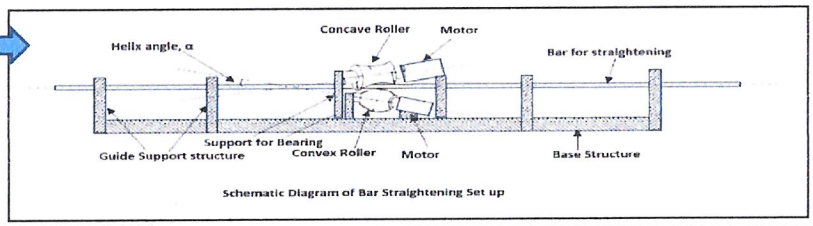


Surface Plot

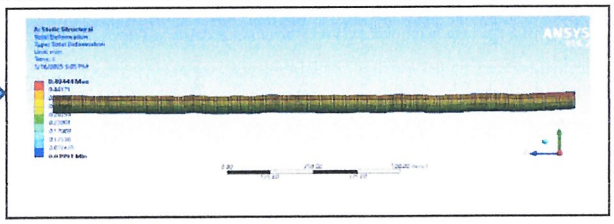


- SPC Analysis for straightness before straightening using Deflection Readings





Schematic Diagram of Bar Straightening Set up



Conclusion after Straightening Process

- Experimental method is very simple and effective to study deformation pattern
- ANOVA is very useful in straightening process for combination of Roller Dia & Helix Angle
- Helix Angle criterion can help in taking decision on process speed and quality
- FEM can be successfully used in deformation study and check validity of statistical results
- RFR model is superior based on Machine Learning for prediction of straightness

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