A Study of Taguchi Method Primarily based Optimization of Cold Rolling Mill Parameter to Improve Quality and Productivity of Steel

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Abstract

Chatter has been recognized as major restriction for the increase in productivity of cold rolling processes, limiting the rolling speed for thin steel strips. It is shown that chatter has close relation with rolling conditions. So the main aim of this paper is to attain the optimum set points of rolling to achieve maximum rolling speed, preventing chatter to occur. Two combination methods were used for optimization. First method is done in four steps: providing a simulation program for chatter analysis, preparing data from simulation program based on central composite design of experiment, developing a statistical model to relate system tendency to chatter and rolling parameters by response surface methodology, and finally optimizing the process by genetic algorithm. Second Method has analogous stages. But central composite design of experiment is replaced by Taguchi method and response surface methodology is replaced by neural network method. Also a study on the influence of the rolling parameters on system stability has been carried out. By using these combination methods, new set points were determined and significant improvement achieved in rolling speed.

Keywords:-Taguchi Method, Optimization, Cold rolling, Productivity, steel.

1. Introduction

Owing to the increasing quality standards, special attention must be paid to the design of roll grinding processes. Besides the quality of the work rolls, the grinding process must be sufficient for economical requirements. The quality of the work rolls depends mainly on technological aspects, like the specification of the grinding wheel, dressing parameters, material removal rate, cooling lubricants etc., which influence the surface roughness. In precision grinding operations, it is often important to set the correct grinding machine parameters so as to produce parts with required quality. In order to decrease the cost and increase the production rate, the grinding machine must be set to operate within the shortest possible grinding cycle time. Hahn and Lindsay (1966) identified the quantitative relationships between the various important process parameters. According to them, grinding performance (surface finish, wheel wear and stock removal rate) will differ from one machine to another, even though the same wheel and work material are used.

Flat rolled strip production employs various types of steel and cast iron work rolls and backup rolls to reduce the thickness of steel slabs to the desired finished product thickness and width of flat rolled strip in coil form. The reduction in thickness employs high forces in both hot mills and cold working mills to elongate the steel bar and strip while delivering the desired physical and metallurgical properties to the strip product. Flat Cold working employs both continuous and semi-continuous Cold working processes in hot mills and cold mills. The critical importance is the thickness control, the shape and flatness, and the surface condition of the flat rolled strip. Variations in quality of these factors can result in processing cost increases, extra maintenance of equipment, production losses, and late deliveries of products to both downstream internal customers and external customers.

2. 2.Literature Review

2.1 Cold Working - Overview

Machining is the commonly used manufacturing process for the production of finished components of desired shape, size and accuracy. Machining process involves the usage of single or multiple point cutting tools to remove the unwanted materials from the stock in the form of chips (Komandurai 1993). Cold working is a manufacturing process with unsteady process behavior, whose complex characteristics determine the technological output and quality.

2.2 Grinding principles

Grinding removes the metal from the work piece in the form of small chips by mechanical action of abrasive particles bonded together in a grinding wheel. Rubbing, Plowing and Metal removal are the three stages of chip removal process in grinding (Rajmohan and Radha krishnan 1990). Grinding is a slow process in terms of unit removal of the stock. Hence, other methods are used first to bring the work closer to its required dimensions and then it is ground to achieve the desired finish. In some applications, grinding is also employed for higher metal removal rate. In such heavy duty grinding operations more abrasive is consumed. In these cases, the main objective is to remove more amount of material that too as quickly and effectively as possible. Thus, the grinding process can be applied successfully to almost any component requiring precision or hard machining and it is also one of the widely used methods of removing material from the work piece after hardening. The process quality depends on a large extent on the experience of the operator. Within the spectrum of machining processes, the uniqueness of grinding is found in its cutting tool. Modern grinding wheels and tools are generally composed of two materials, one is the tiny abrasive particles called grains or grits which do the cutting and the other is a softer bonding agent to hold the countless abrasive grains together in a solid mass (Figure 1).

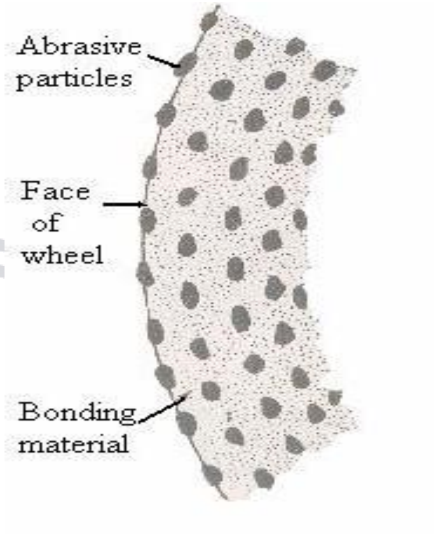

Figure 1 Grinding wheel showing edge of abrasive grains

The structural arrangement of the abrasive grain and binder can greatly affect their elastic properties. Brecker (1974) analysed bond formation during firing of vitrified wheels and observed the cross section of the wheel, from which he concluded that surface tension forces are sufficient to draw the abrasive grains into direct contact.

When high accuracy of the work-piece and the automation of the grinding work are considered, it is necessary to secure the reliability and the reproducibility for grinding wheel as a cutting tool. For this purpose, it is important to choose a grinding wheel of uniform grade. However, irregularity of grade changes the grinding characteristic on the working periphery of a grinding wheel locally and it affects the dimensional accuracy of work-piece (Shinichi Tooe et al 1987).

During grinding, material is removed from the work-piece surface in the form of small chips by the abrasive particles on the grinding wheel. The material removal can be visualized by considering a single abrasive grain on the wheel (Figure 1). As the grain makes contact with the work-piece surface, the depth of cut is zero.

When the grain is at P it is just contacting the work- piece and the depth of cut is zero. In unit time T, the grain will advance to position R. In the same unit time T, the point R on the work-piece would have come to position S. The point S will be very near to the point R, since the rotation of the wheel is much faster than the work. The chip section removed is represented by PRS. The maximum depth of cut represented by SU is the maximum chip thickness per grit (or) the grain depth of cut (gd).

3. Experiment Details and Measurements

The experimental investigation was carried out on the work rolls used in the sendzimir mill and these mills are known for their ability to roll extremely hard materials to very thin gauges. The pyramid configuration of the back-up rolls transmits the roll separating force along the length of the work rolls, through the intermediate rolls, to the backup assemblies and finally to the rigid mono blocks housing. Rolls are tools used in Cold working mills to reduce the cross section of metal stock and take all kinds of stresses; loads from normal and abnormal cold working and changing with roll wear during a Cold working operation.

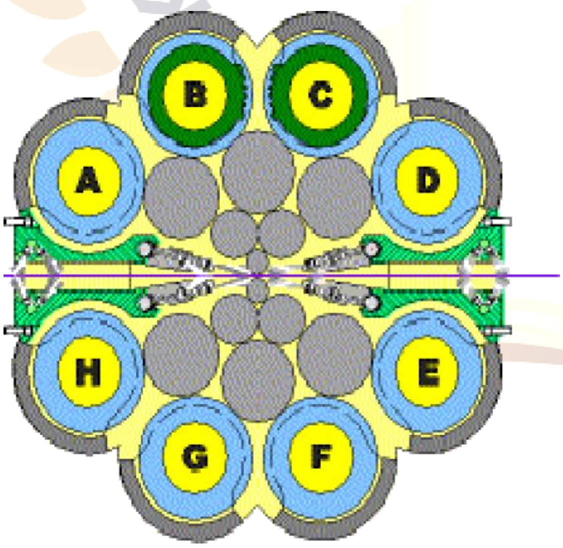

Fig. 2 Schematic diagram of Sendzimir Cold working mill

3.1 Machine

Experimental investigations have been carried out with varying depth of cut, feed, speeds and number of passes for rough work rolls and for the finish work rolls varying the dressing parameters also been included to obtain fine finish in a roll grinder. For the attainment of good surface finish with high hardness, a SHIBAURA roll grinding machine as shown in Figure 3.2 with silicon carbide grinding wheel for finish work rolls and self-sharpening wheel for rough work rolls is employed. The roll grinder selected is a semi-automatic machine and commonly used in steel Cold working industries. In this study, the parameters are varied according to an orthogonal array's used in different experimental conditions based on Design of Experiments. Both rough and finish rolls regularly redressed to rebuild the desired shape and to eliminate the worm, fire cracked and fatigued surface.

4. Work Roll Material

The rough and finish work rolls are made of High carbon high chromium D2 forged and hardened Steel. These work rolls are produced from electro slag refined steel and is forged on a 3000 tonne or 1000 tonne open die forge. The forgings are immediately annealed to remove internal stresses incurred during the forging processes. The forged work rolls then hardened up to HRC 60.

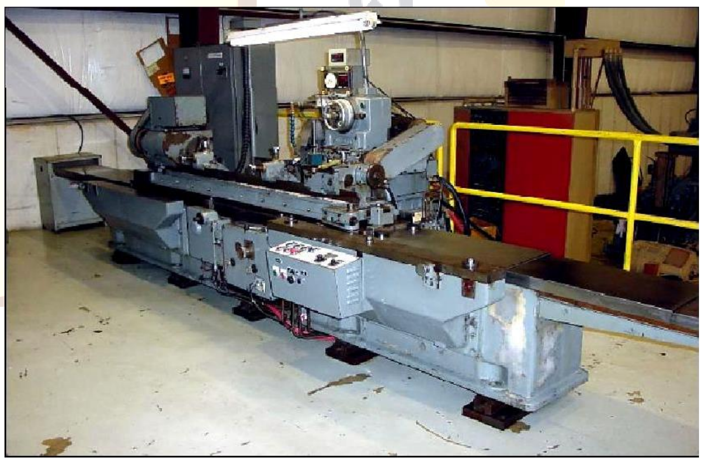

Fig. 4 Shibaura Sendzimer Roll Grinder

5. Estimation of Chemical Composition

Chemical composition of the work roll materials is analyzed with optical emission spectrometer (Figure 3.3). Sample preparation is extremely important when analyzing samples in a spectro-lab. The work roll materials are generally ground using a band or disc grinder. A 60 grit paper is recommended. The spectrometer works on the principle of optical emission, and its specifications are given in Table 3.3.The chemical composition of work roll material is presented in the Table 3.4.Thermo-Mechanical properties is presented in the Table 3.5.

6. Development of Mathematical Modeling and Multi Objective Optimization of Cold Working Operation Using Response Surface Methodology and Genetic Algorithm

In order to predict component behavior during use or to control the grinding process, it is necessary to quantify surface roughness, grinding power and material removal rate which are the most critical quality constraints for the selection of grinding factors in process planning. The process set-up often depends on the operator competence. However, an efficient process set-up should be model based and should guarantee a steady process in which the required surface roughness is obtained.

6. Methodology

In this work, there are six controllable parameters for which, the modelling is based on Box-Behenken design of experiments and response surface methodology, which is an efficient statistical technique to determine the coefficients that assure the best fit of the predictive polynomial, includes square and interactive terms. For solving multi-objective optimization problem, the weighted sum method has been employed to find out the pareto - optimal solutions. Considering the merits of Genetic Algorithm (GA), this work has been made an attempt to use the Genetic Algorithm for the optimization of operating parameters for the work roll grinding process.

7.2 RSM Mathematical Formulation

The data collected from the experiments were used to build a mathematical surface model using response surface methodology. The RSM is a collection of mathematical and statistical techniques that are useful for modeling and analyzing problems in which response of interest is influenced by several variables and the objective is to obtain the response. The design procedure of RSM is as follows:

Designing of a series of experiments for adequate and reliable measurement of the response of interest.

Developing a mathematical model of the second order response surface with the best fittings. Findings the optimal set of experimental parameters that produce a maximum or minimum value of response.

Representing the direct and interactive effects of process parameters through two and three-dimensional plots. If all variables are assumed to be measurable, the response surface can be expressed as follows,

$$y = f(x_1, x_2, \ldots x_n) \qquad (1)$$

The goal is to optimize the response variable y. It is assumed that the independent variables are continuous and controllable by experiments with negligible errors. It is required to find a suitable approximation for the true functional relationship between independent variables and response surface. Usually a second-order model is utilized in response surface methodology.

Where ε is a random error? The β coefficients, which should be determined in the second-order model, are obtained by the least square method.

In general equation (6.2) can be written in matrix form.

$$Y = bX + E \quad (2)$$

Where Y is defined to be a matrix of measured values, X to be a matrix of independent variables. The matrixes b and E consists of coefficients and errors, respectively. The solution of equation (3) can be obtained by the matrix approach.

$$b = (X^T X)^{-1} X^T Y \quad (3)$$

Where X^T is the transpose of the matrix X and $(X^T X)^{-1}$ is the inverse of thematrix $X^T X$. (4)

7.3 Box-Behenken Design Matrix

The most popular response surface methodologies are central composite and Box-Behenken designs. Box-Behenken design is an efficient and creative three-level composite design for fitting second order response systems. It is an independent quadratic design in that it does not contain in an embedded factorial or fractional factorial design. The methodology is based on the construction of balance designs, which are rotatable and enable each factor level to be tested several times. Each factor or independent variable can be placed at one of three equally spaced values coded as (-1, 0 and +1). In this design the treatment combinations are at the center. The spherical nature of the Box-Behenken design,

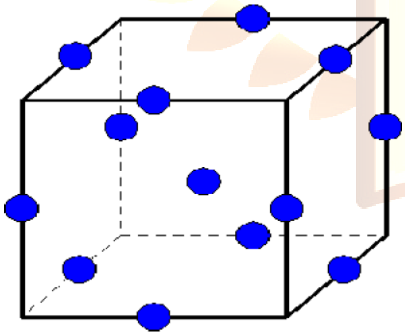

Figure 5 Box-Behenken Design

Combined with the fact that the designs are rotatable or near rotatable, suggests that ample center runs have to be performed. The Figure 5 demonstrates the Box-Behenken design.

(6.3)

In this work, a Box-Behenken matrix design including 54 experiments was applied for evaluation of six controllable grinding parameters each in three levels.

Conclusion

(6.4)

The accuracy and consistency of obtaining the surface roughness in work rolls are so important in steel industry that it may reflect on the quality of the rolled sheet metal during Cold working process. The combined ANN model and Taguchi Technique described in this work for obtaining the optimal machining conditions for achieving desired surface roughness on rough, finish work rolls could provide an improved generalization capability over the statistical Taguchi Technique.

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