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Energy Efficiency in a Steel Rolling Mill by Effective Planning (Case Study)

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Abstract: *The recent years showed a significant increase both in energy costs and social awareness for Environmental concerns. The present paper describes how the material flow study may powerfully support production planning and the related decisions. The application proposed refers to a steel Rolling plant. The optimization of the production plan and Equipment is pursued by an objective function which takes into account both traditional targets and the need for an efficient use of energy. A typical working day for a rolling mill operator is not as straightforward as one would think. In fact a typical day can often mean a turbulent one where the operator has to battle process instability that interferes with production. Finding his way out of certain situations such as unstable rolling, which results in down time, less yield, and frequently the appearance of cobbles as a result of bar derailing, may be very time consuming. A typical working were implemented to forecast energy requirements at the Continuous and Cross country Rolling Mills. Final results showed how the effective planning support may lead to a significant reduction (more than 20%) of the daily consumption of electric energy. Regaining stable rolling is often based on the individuals' experience. Judging what the best set of process parameter settings should be is a black art representing the very core of their professional pride. However, by the time production is back on track, valuable material and energy have been wasted in ensuring correct dimensional accuracy usually through trial and error. To aid operators in their task as well as to eliminate such waste, study of the effective planning help for advanced rolling process optimization.*

Keywords: *Dimension, Cobbles, Down Time, Unstable Rolling, Energy efficiency.*

I. INTRODUCTION

In the most recent years, the need for a more rational and efficient use of energy has emerged as a strategic and urgent issue. Such a necessity is particularly perceived in the industrial sector, not only because of the increasing costs of energy, but also as a consequence of the global competition, which stresses some features of the process and its final products (e.g.cost and quality). Furthermore, the rational use of the energy resource may be regarded as a twofold issue, a first aspect being related to the achieved consciousness of the limited availability of energy, regarded as a source, and the second being represented by a mature appreciation of the costs born to procure energy. In fact, according to a wider and wiser view of the problem, the term “cost” is to be appreciated not only in economic terms, but also in its social and environmental features.

Therefore, the concept of “sustainability” is to be accepted and introduced in the industrial practices, as a consequence of the need for a limitation in the amount of energy required by human activities, so as to avoid to compromise the future of next generations. In a similar scenario, “energy saving” covers a fundamental role, as this approach to industrial processes focuses on the capacity to control activities and practices reducing energy wastes (Cheung and Hui,2004). Such a concept introduces a peculiar dimension of energy efficiency, as it implies a reduced use of energy sources, possibly integrated by the valurisation of energy residuals, to carry out the same activities. The aim of the present research is to show the effective planning and the implementation of a suitable practice to increase the energy efficiency in industrial plants, with specific reference to the case of steel Rolling mills. Regardless of the industrial sector taken as reference, the approach presents a more general validity, as the final result of the research shows how the simulation of the industrial process may provide an effective support to the formulation of energy-efficient and sustainable production plans. In general, steel plants are subjected to significant costs, due to energy consumption, which, therefore, highly influence both product and service costs: increasing energy efficiency may be an ineluctable way to maintain competitiveness. The topic described is particularly relevant to the Province of India where the steel production is carried out mainly by mini-steel plant. Presently, the largest part of these industrial structures are organized according to “mini steel” plant schemes, which allow production plans arranged on small batches of even differentiated steel types. The type and quality of the steel produced may be varied several times per day. Such an increased flexibility is necessary to match market demand, as a make-to-order approach is generally considered as the most effective production strategy, given the high costs of raw materials and semi-finished products which have magnified stocking costs. The energy-related components significantly contribute to the overall accounting of production costs , in particular, the need for differentiated production, short lead times and precise delivery dates have further determined the industrial interest for the mini-steel plant configuration. However, a similar approach also implies the need for advanced tools, so as to support production planning and decision making in a complex environment characterized by several parameters, numerous interacting variables and mutual constraints.

II. BACKGROUND

A product change generally refers to the process of changing one stable rolling configuration for one material with specific finishing dimensions to another configuration with a different material and finishing dimensions, with minimal downtime and scrap production. Frequently, the number of rolling stands is also varied. An unsuccessful product change may result in production delays of more than one hour, whereas a successful one is usually completed in a matter of minutes. The difficulties of repetitively reproducing a product change with minimal disruption have challenged industrial researchers, who now have responded with a study of effective planning for operators. Systematic study by simulation and statistical methods, that guide the operator to optimal process parameter settings for stable and dimensionally accurate rolling.

The literature in the field of industrial plant energy efficiency may be essentially divided into three categories:

1. Plant design optimization
2. Operational plant management: scheduling, maintenance, etc..
3. Optimized plant revamping

It is not possible at all to find models universally applicable, they are mainly devoted to specific sector and often designed "ad hoc" for a given case study. The differences between the various types of industry requires a distinction to be effective and potentially applicable. The area most affected by studies is the petrol-chemical: this outcomes is easily justified. One of the most recent issue is related to the effort on how to extend the current analysis to all areas now that the energy problems are increasingly important in each sector. The most frequently used technique for the optimized design of total site utility systems is the tool proposed by Papoulias and Grossmann (1983), that is mainly based on a super-structure of the system. The models for the operational management are mainly focused on the problems of choice in the distribution of the load on units of service and the scheduling of maintenance. The problem is mainly treated recurring to mixed linear programming models (MILP). Examples refers to the work of Iyer and Grosmann (1997, 1998): the objective is the minimization of costs on an annual basis, through the search for a multi operational programming optimum period. Another approach, in the literature, is the simulation. In the case illustrated by Prasad Saraph (2001) has tried to solve the problem of water in a biotech industry: the variability of industrial process together with a lack of planning for the provision of service led to interruptions in production due to lack of water.

One of the most popular techniques for the plant revamping optimization is the pinch analysis. The primary objective of pinch analysis, regardless of the field where it is applied, is to optimize the use of materials or energy, achieving economic and environmental benefits. A powerful tool for optimizing energy in the industrial, which also exploits the pinch analysis, is the SitEModellingTM (Wolff et al, 1998) In the literature on steel production there are several paper focused on energy reduction of the plant, on of the most relevant is Larsson and Dahl (2003) where a model based on an optimizing routine is proposed. The main idea is to make a total analysis method for the steel plant system including the surroundings. The model is used to analyze the different possibilities for energy savings and practice changes within the system. The effect of optimizing the total system versus separate optimization of the different sub processes is illustrated.

III. PROCESS DESCRIPTION

Here general process of a mini-steel plant will be described, according to the flow diagram in figure 1.In this section we describe the machines of the rolling mill and their interactions rules following the production flow. The department under consideration produces different kinds of steels obtained using specific reduction processes. The department is formed by Reheating furnace, 20 Stands continuous mill, Cooling bed, garret and block mill. For the production of special size steels it is used a Garret , Block mill. Moreover, in order to understand correctly the system analyzed, it is important to consider that the rolling stand is the bottleneck of the department, because it has a more energy consumption than the other stations**.** Another important variable is the reheating furnace that can be consumed more power in air blowers. Summarizing, the objective of the effective planing to set the speed and blower and furnace temperature in order to get the required temperature and minimum power consumption in air blower.

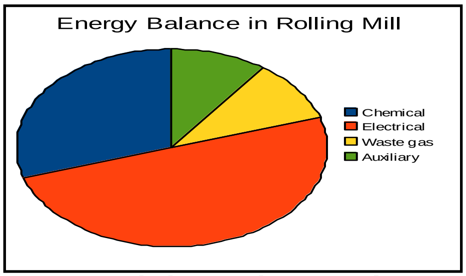

Figure 1: Steel Plant Production – Flow Diagram

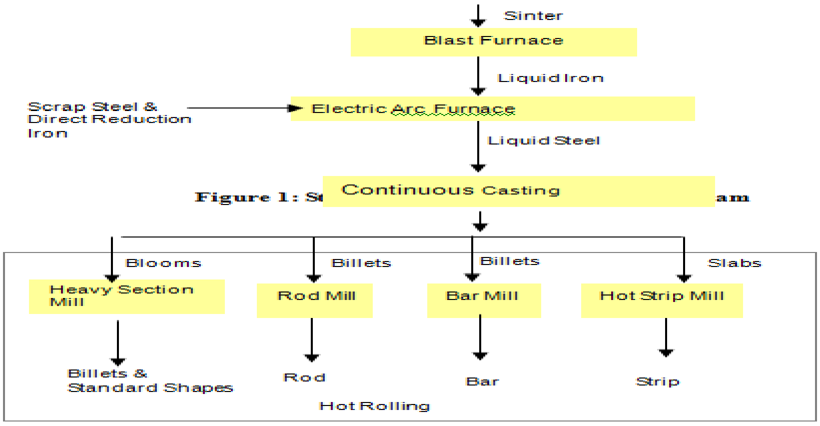

Figure 2: Energy Patterns in Rolling mill and Reheating Furnace

In the steel rolling mill first the Billet heated in the reheating furnace then it pass through the no of passes to convert it into the required size. The reconditioning of the product done at the various bright bar section. Rolling Mills Analyzing the steel flow diagram of the mini-steel plant. Mainly the maximum power consumption takes place at the different stands used for rolling.

III.1. Requirement of Energy

A typical energy distribution of the modern rolling mill is shown in Figure 2.

Depending upon the rolling mill , about 75 to 80% of the total energy is Chemical and electric. While the remainder is lost to the, waste gas, Hydraulic, lubrication and cooling. Just a decade ago VFD introduced and can be used for the optimization of the furnace combustion air requirement and Auxiliary power requirement system. This will reduced the power consumption by 20 to 30 %. Continuing advancements in Rolling Mills technology now make it possible to optimize the size of the motor and cooling system can achieve the same performance and consequently a lower Energy consumption.

IV. THE SYSTEM TO BE ADOPTED

Models for optimization, simulation and calibration: Mill availability and yield will certainly improve by being able to model, simulate, and optimize production speed and energy requirements, while controlling bar dimension, roll load sharing, groove utilization, and similar important product change quantities. The on line data available to the mill floor worker – via an easy-to-use HMI – about the parameter settings that should be used to reach optimal conditions. With this complex calculations take less than 6-7 minute to complete, but in actual fact most are often completed in no more than ten seconds. This can be accessed through an auxiliary PC located in the operators' control room alongside the regular ABB Rolling Mill Control (RMC™) and Inter stand Dimension Control (IDC™) displays.

Inter stand Dimension Control for rolling stability: The IDC concept has been developed for rod and bar mills to achieve tighter tolerances head to tail, as well as improved product quality, yield, and availability. In addition it ensures fast product and dimension changes. It functions as an early indicator of abnormal mill conditions, which ensures a more consistent mill set-up and improved pass schedules. The key IDC component is the on line bar dimensional measurement. On line information from the drive system and seamlessly communicated to the operator. The operator can take corrective action by few parameter settings (selected by the operator) required for various process simulation and optimization tasks. Setting time for the operator is very less due to this information.

Stable rolling is defined by a continuous mass flow rate throughout the process line with minimal inter stand forces, and in particular compressive stresses: This configuration in combination with high speed algorithms allow for a great number of interactive process optimization tasks in a short period of time. Having identified parameter settings that meet his demands, the operator can store these results as a new RMC rolling schedule for retrieval at some later date. In summary, the ADM tool requires only minimal configuration work before it starts delivering useful results.

Rolling maximization and minimization: Stable rolling is defined by a continuous mass flow rate throughout the process line with minimal inter stand forces, and in particular compressive stresses. Maintaining this together with the required dimensional accuracy of the finished product challenges the operator's skills. The ADM tool provides additional capabilities to assist the operator in fully understanding changes that occur in the state of the current rolling, and to plan for the optimization of an upcoming production run. With this tool stability and product dimensional quality are ensured and a vast number of related and important aspects previously beyond the reach of the operator can now be controlled. The maximization *or* minimization of selected production aspects while keeping related and dependent aspects within permissible constraints

What cause derailment or cobble: Derailment happens because of a mass flow mismatch, which occurs when an upstream pair of rolls "feeds" more material per unit of time than the neighboring downstream pair of rolls is able to "swallow". The underlying cause of derailment is a lack of quantitative understanding as to how various process parameter settings (roll gap, motor speed, inter stand tension etc.) affect bar deformation in the roll groove and hence the process mass flow. In mills with frequent Product Changes and small batches there is a risk of several such events per day.

Energy consumption minimization: Minimizing energy consumption is one such optimization choice available to the operator, while at the same time allowable upper and lower limits are defined for bar width, area, speed, inter pass tension, roll gap and motor speed. The finishing dimension and speed of the production to be analyzed is always prescribed without the need for user intervention. Using the selected aspect values the ADM optimizer then solves this nonlinear minimization problem and returns the optimal rolling energy consumption value, or power, as well as the influence of the determined optimal parameters (usually roll gaps and reduction factors) on width, area, tension, etc. The complex dependencies between process parameters are handled by consistent rolling models linking mass flow, spread, inter pass tensions, torque and power. Controlling bar width and area, so called groove utilization control, is not only of importance when reducing roll wear, but it also plays an important part in preventing damage to the bar by ensuring it does not overfill the roll groove. Should the user by accident define inconsistent parameters leading to a solution exceeding one or more of the parameter bounds, a solution diagnostics procedure advises him how to obtain an admissible solution.

Other optimization objectives include: The maximization of production speed. Again system limits such as maximum available motor power, torque, and speed are set as well as limits defined at the operator's discretion based on his experience and knowledge. The matching of individual stand powers to predefined targets, so called load leveling. The matching of individual bar widths and cross section areas, also with predefined targets. The latter case is of concern when groove utilization control is the primary goal of optimization. Objectives, constraints, and process parameters controlling thermodynamics and micro structural properties will be included.

The simulation functionality of the tool allows quantities such as bar width, area and speed to be quickly calculated. It also allows sensitivity analyses to be performed.

Inter pass tension modeling: In all optimization selections the inter pass tension plays an important role and constraints ensuring stable rolling without compressive stresses may be specified, as well as tension set points. A unique modeling feature is the way in which tensions change bar dimensions, both in the deformation and inter stand zones, while at the same time the overall model maintains a continuous mass flow. This is not only violated in other modeling approaches, but it also paves the way for a consistent analysis of the so called "endless rolling", in which bar dimensions may be controlled by relatively high inter stand tensions.

Model adaptation: Optimization may be carried out either for the current production run or for an upcoming one following a Process procedure. For a current run, on-line drive system and on line-gauge readings are used for model adaptation so that model accuracy is enhanced. Calibrated models from previous production runs may also be used in the Process optimization provided their rolling conditions are similar. It is required to automatically decides the best model adaptation scheme. It is common knowledge that a rolling power model greatly benefits from adaptation and this in turn affects the accuracy with which energy consumption is determined. Process parameter inputs include roll gaps and motor speeds, along with information on billet and roll grooves. This feature is very useful when analyzing the effect of small changes or disturbances to the process parameters obtained in an optimization – so called *sensitivity analyses*. One simulation task requires a few tenths of a second for a 20-stand configuration.

A statistical approach with uncertain materials and process conditions: Suppose a new material with uncertain materials properties (essentially its flow stress or resistance to deformation) is to be rolled the first time. To check for potential problems the operator may want to investigate for example the safety margins with respect to unstable rolling. A *statistical evaluation* of the likelihood of inters pass tensions exceeding allowable ranges. The core of this feature is based on the well known Monte Carlo approach, which has been adapted to the rolling models in a novel way. Results are presented as a probability of stable rolling for the configuration and process parameters at hand. In fact, all types of results pertaining to the bar, rolls and drives previously discussed may now be expressed as confidence intervals with lower and upper limits, rather than as one specific value obtained in a regular deterministic simulation. This also improves the accuracy of the energy requirement prediction as this is very sensitive to bar materials deformation properties.

Towards on-line optimization: Further reduction of optimization times towards just one or two seconds is within reach using the latest numerical optimization developments. A fully automatic on-line optimization tool is envisioned thus alleviating the need for trial billets. To be more precise, optimization and adaptation is carried out during the time the bar head travels between the first two stands in a multi stand rolling line.

V. RESULTS

The results obtained after implementing the optimized planning described. In particular we show in figure 3 the electric energy consumption reduction obtained at the rolling mill. The oil consumption reduction shown in the fig 4 for reheating furnace.

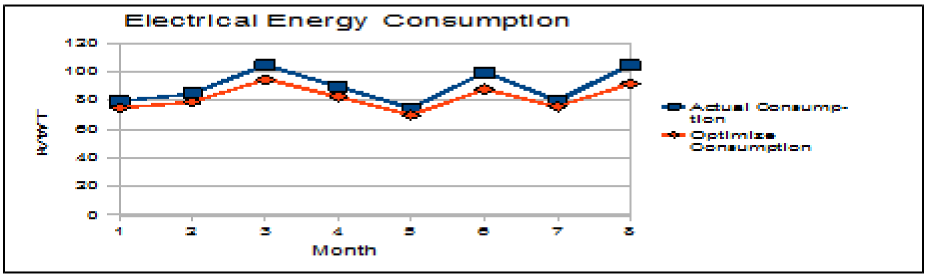

Fig3 Comparison between the optimize energy consumption and real energy consumption

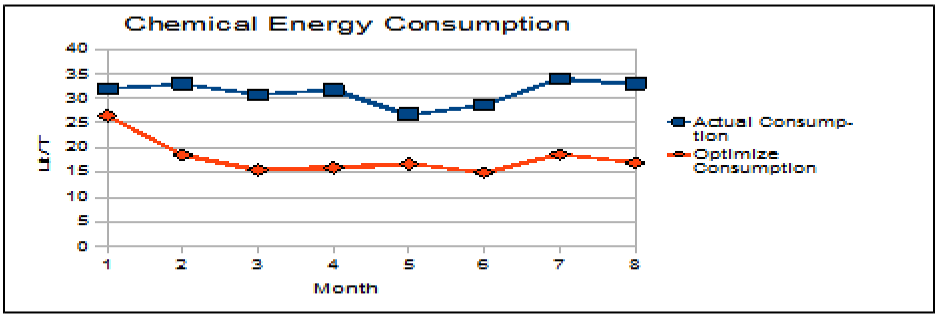

Fig4 Comparison between the optimize oil consumption and real oil consumption

It is important to note that with the higher section the reduction of the electric consumption are not so significant because these sizes have the less no of stands in rolling. In these cases the holding time is already reduced because the rolling rate is fast. The only benefit of the optimization in the case of stands is the right choice of the stands speed. Observing the results, we obtain a mean reduction of electric consumption of 21%at the rolling mill.

VI. CONCLUSIONS

In the present work we have proposed a sequence of rolling to avoid the mill down time for pass change, sample checking and stand change that has the objective to set the speed and the holding time at the rolling mill in order to produce the sequence defined by the planning system so as to reduce the electric energy consumption. Effective planing will avoid the furnace down time for maintenance and rolling schedule. Predefined down time will help the operator to reduced the temperature and this will result in the less oil consumption. The use of wast gas in the Mini blast furnace will help to reduced the oil consumption in the reheating furnace by perfect synchronization with blast furnace operating. Results obtained support company's to optimize the usage of strategic leverage. In particular the overall electric energy saving is larger than 20% and oil saving is larger than 30%.

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