ARE YOU GETTING THE MOST FROM YOUR ROLLING MILL? HOW TO USE YOUR MAIN MILL MEASUREMENTS TO TARGET INCREASED MILL UTILIZATION[1]

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Abstract
Production efficiency is always a driving factor as rolling mill operators, and in turn rolling mill suppliers, are forced to produce their products more cost effectively. Critical areas can be optimized providing tremendous benefit to the operation of the rolling mill with easily justifiable investments. By analysing the current status of key measurement areas in the rolling mill, latest maintenance practices and equipment technology can be easily retrofitted into existing, older operations, improving overall efficiencies. Using proactive planning, critical mill areas can be easily identified and improvement plans put in place. The results of these activities increase your mill utilization and achieve maximized performance from your current mill and personnel investment.
Key words: Rolling mill; Upgrade; Efficiency; Maintenance.

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Introduction

The vast majority of long rolling mills in the world all base their mill performance on a few critical operating measurements. The operating year is scheduled with a target number of productive operating hours planned based on the local market conditions and targeted tonnages to be rolled. Once these targets are set then the individual metrics and benchmarks are defined.

Individual tracking of key metrics including, but not limited to, yield, cobble rate, delay times related to electrical equipment, fluid systems, mechanical equipment, and operational issues, as well as total mill production rates can be used to identify areas for targeted improvements. As mills expand their product mix, production rates, steel grades, etc. in reaction to market demands the mill equipment is exposed to operating conditions outside the original design parameters. These conditions have negative impact on overall equipment reliability.

Measurement without planning and action is a waste of time and effort. In the following pages we will review some critical mill measurements and review some of the ideas and activities that Siemens VAI LR Services has used to help customers to operate with increased mill utilization.

Key Measurements

The three main measurements that can indicate the efficiency of a rolling mill are yield, cobble rate, and utilization rate. What is considered to be a reasonable operating baseline? In our experience dealing with various types of long rolling mills a well run and potentially highly profitable mill operates with yield rates at 96-97%, cobble rates < 0.4%, and mill utilization rate targets at 80-90%. Certainly there are exceptions to these values for different plant types but these can be used as typical baselines for bench marking comparisons. For simplicity here we will assume the reader understands the basis of how they are measured.

Yield

The yield is a basic indicator of how much processed steel could be sold. Small improvements, even 0.5%, can provide a great deal of financial improvement directly to the rolling mills profit. The control of scale as it relates to yield is beyond the scope of this paper as it is a topic that leaves the rolling mill and gets into steel making and then later to billet re-heating. While the operation of the reheat directly relates to the control of scale formation as the billets enter the rolling mill we will not touch on this topic.

A key area is the functionality of the mill shears. Proper setup and optimization of the shear head and/or tail cuts can greatly improve the rolling success of certain grades of steel, reducing cobbles caused by poor formation of the ends of the rolled bars. Each mill needs to commit the time to getting the proper operational settings to maximize the yield of their products. Lastly, another main contributor is related to losses coming from poor quality control. Yield losses related to quality rejections are the most costly to the rolling mill because the complete conversion cost for the finished product has already been realized. Many quality rejections can be avoided, or greatly minimized, by detailed review of all equipment that guides the material through the entire rolling mill.

Cobble Rate

Cobbles are the most fundamental of indicators. Did the billet pass completely through the rolling mill? What is the frequency of when this event does not happen? A small improvement in the cobble rate quickly translates into reduced operating costs and therefore more profitability for the mill. Unfortunately this measurement can sometimes force behavior in the mill that can limit the total productivity of a plant. In some cases a mill can achieve a targeted cobble rate, or only focus on the cobble rate, and thus reduce some of the incentive or motivation to improve many mill areas. Changes to practices, procedures, and equipment that could have a short-term negative impact on cobble rate are sometimes avoided or dismissed without looking at the long-term overall benefits to the mills utilization and profitability. To not fall into this "trap" a detailed review of what is the root cause of the cobble is needed to have a clear understanding of the measurement and what it means to the rolling mill operation.

Utilization Rate

The utilization rate of the rolling mill is the ultimate indicator of its operational performance. Within the utilization measurement there are a large number of separate measurements that can be analyzed for targeted proactive improvements. By reviewing the mill operating delays across various disciplines and functional areas critical issues can be identified and addressed for corrective action.

The primary cause of operational delays is cobbles. Often times, cobbles are related in some way to the guiding equipment and ancillaries. Tracking and logging operational delays that occur from cobbles will highlight problem areas in the rolling mill and can focus attention into the smaller details. An audit of the roll shop practices when preparing the guides will ensure the equipment is properly prepared and maintained for the required rolling campaign. A review of the guide mounting equipment and alignment methods in the mill can also be an indicator of the equipments proper use and maintenance.

Maintenance delays are defined by the unexpected failure of a piece of equipment within the rolling mill line that prevents operation. Tracking and classifying the types of delays leads to focus areas that can be improved by advanced maintenance and equipment technology.

Mechanical delays occur when equipment fails outside of a planned maintenance schedule causing a decrease in utilization. These failures occur in the primary drives, mill stands, and auxiliary equipment and include failures of bearings, seals, mechanisms, actuators, couplings, etc. Mechanical failures can be classified as easily repairable and catastrophic. The first category can be repaired by normal rebuild and replacement of consumable components like seals and bearings. Catastrophic failures include major component failures like shafts, gears, housings, etc that are not typically considered as stock or short lead time mill spares. Although the goal is to avoid any and all unplanned failures, catastrophic failures must be avoided. The key for prevention is early detection through predictive maintenance practices.

Fluids system delays includes the failure of a water, oil lubrication, air/oil lubrication, grease, hydraulic, or pneumatic system to provide the specified flow rate of the fluid at the prescribed pressure and temperature. Through the years system complexity has increased to handle the wide range of operating conditions that cause extremes in heat load from mechanical losses as well as variable ambient conditions. As is the case in mechanical failures, early detection of any failure is critical. For example; the inability to consistently provide lubricating oil at the proper temperature will directly affect the oil viscosity reducing the life of critical components and possibly lead to premature failure.

Electrical delays, which are typically related but not limited to interlock issues, speed setting or equipment sequencing, drive hardware, and sensors can also be major contributors to mill delays. While sensors and similar devices may be damaged in their normal operating environment making failure difficult to predict major items such as motors and drives can provide tremendous benefits when included in predictive and preventative maintenance programs.

l equipment has a finite period of ideal serviceable life. Mill builders typically design for rebuild of equipment on some nominal cycle to avoid instances of catastrophic equipment failure. Operating conditions and maintenance practices will have a positive or negative affect on this nominal life. All mills are different and have varying standards of acceptance for service life. The key in proactive planning is to know the life cycles of the critical components in your equipment and schedule based on this knowledge to prevent/minimize unplanned break downs that decrease mill utilization. In all cases, root cause analysis is essential to prevent reoccurrence and is a critical step in any proactive maintenance program.

Proactive Planning

Operational Review

Focusing on the cobble reports and understanding the causes of the delays are critical for reducing the operational delays in the mill. Since guide equipment is often the cause of the cobble, additional investigation is needed to get to the true root cause of the issues. Guide design is a topic that will always be a subject for discussions as different opinions and practices make the guide equipment an area that can always be debated. While this point is true the basic design requirements remain the same but they need to be reviewed when ever a change is made to the rolling mill or process.

While most mills look to the roll shop as a source of guide delays in the mill the mechanical equipment and the specific rolling process must also be reviewed and considered. Maintenance plans must be made and followed for the guide mounting equipment just like the mill stands, bearing chocks, etc. Poor equipment condition and position for the guide mounting equipment can lead to repeated guide failures and quality problems. Periodic checks should be made during downtime periods to ensure the fastening hardware for the guides and restbars are in good condition and are properly tightened. Scale and debris should be removed whenever possible to keep the equipment in good operating order. The clamping and alignment surfaces need to be kept clean and free from damage. If a cobble occurs a few extra minutes should be taken to make sure the guide is properly set to the mill roll groove. Incorrect setup of the guide or restbar results in premature guide wear or failure, poor product quality, cobbles, and other adverse effects.

Guides are not just the equipment that is mounted to the mill stands. All equipment that carries the rolled material through the rolling mill “guide” the material. These “guides” and their supports must be maintained and kept in proper operating condition. Paying careful attention to equipment alignment throughout the entire rolling mill minimizes the chances that rolled in flaws and surface defects are

minimized so quality problems do not arise from these defects. Periodic checks of the mills installed alignment conditions will allow the mill to operate at maximum speeds while guiding the material on a consistent basis.
Periodic review of the detailed design and condition of the static guides, roller guide rollers and static inserts must be made to confirm the intended design shape and dimensions. Worn or incorrect parts can cause issues with the passage of the head of the bar through the rolling mill that can lead to guide failures and cobbles that can cause damage and unplanned down time for the mill.

Predictive Maintenance Practices

Until the 1980's, predictive maintenance was not a readily accepted practice. Seen as unreliable, unproven and unjustified, many mills chose to follow preventive maintenance practices or just allow their equipment to "run-to-breakdown". However the past decade has proven that the theories involved in predictive maintenance practices are truly applicable to long rolling mills and can provide a significant competitive advantage in the marketplace when applied correctly. Today most mills realize the importance of designing and implementing a predictive maintenance program but they do not know how to initiate the program implementation. The following sections highlight the physical and financial differences between the differing strategies and provide some insights into methodology.
The first type of maintenance is reactive or "Run-To-Breakdown" which simply means that equipment is allowed to operate until an element of the system fails and the system can no longer operate effectively. This is the most costly maintenance strategy available due to excessive damage to equipment, increased consumption of spare parts and extended mill downtime. Reactive maintenance provides the minimum control of scheduled maintenance tasks and exposes the mill to replacement of significant, higher cost components such as housings, shafts, gears and gearboxes, etc. Once a mill has operated on a prolonged basis in a reactive maintenance mode the task of shifting to a preventative mode can seem overwhelming with all of the reactive activities consuming the mill personnel and consuming operating costs.
The next level, preventive maintenance, is the practice of periodically replacing machine and system components at scheduled intervals in anticipation of possible failures. Preventive maintenance techniques lead to two possible situations:

1. Premature failures will be undetected, increasing the probability that other critical components will be damaged.
2. Bearings will be changed before they are required. It is now understood that inappropriate time-scheduled maintenance often increases the risk of failure by reintroducing infant mortality to stable systems or introducing problems during the disassembly and reassembly process.

This is a long standing practice for many mills that have historically good operating conditions and processes. Optimization of practices in these mills often entails the introduction of predictive maintenance plans to increase the efficiencies of critical rolling mill components.
Predictive maintenance (PDM) is the practice of using non-invasive techniques, from known machine parameters, to predict the failure of a machine or system. Predictive maintenance programs are designed to identify and adapt to the failure modes for each machine, component, or system. A successful predictive maintenance program will result in reduced spare parts inventory, fewer catastrophic failures, increased productivity, and more efficient and effective maintenance planning.

PDM is based on the practice of comparing the trend of measured machine parameters against known engineering limits and professional experience for the purpose of analyzing, detecting and correcting equipment problems before failure occurs. Examples of machine parameters include temperature, pressure, vibration and current, to name a few.

Although there are many forms of predictive techniques for understanding the health of the equipment as it relates to “best maintenance practices”, we will focus on lubrication techniques, vibration analysis and also failure analysis as a proactive approach to determine the ultimate causes of equipment failures.

PDM tasks are performed while the rolling mill is on-line, not requiring any stoppage of rolling or any decrease in normal production. These techniques provide an advance warning for potential problems allowing for scheduled maintenance planning well in advance and with no disruption to production schedules.

The most important benefit of predictive maintenance is a significant increase in mill utilization, mainly due to the fact that machinery condition is known at all times. This allows repairs to be scheduled, avoiding any production losses due to unplanned mill downtime. Also maintenance costs are noticeably reduced as a result of efficient planning of maintenance tasks. These cost reductions are the result of cost effective use of downtime, planned use of manpower, reduction of on hand spare parts inventories, and planned upgrades or improvements to equipment at the time of scheduled maintenance.

The most common reasons for not adopting proactive maintenance practices are typically:

- Limited manpower
- Too busy in reactive mode to be proactive / strategic
- Lack of understanding strategic value
- Level of employee training

However, based on our experience, the realized benefits of implementing a proactive maintenance program greatly outweigh the cost and effort.

<u>Lubrication Techniques</u>

The lubrication system function is to provide a reliable source of oil to the load-carrying elements, bearings and gears, of the mills various drive trains at a specified quantity, temperature, and cleanliness.

The analogy that the lubrication system pumps the “blood” to the “body”, oil to the mill equipment, is very true. Without a properly functioning heart your bodies’ organs fail much like the mill equipment fails when the oil system is not maintained. Most high speed equipment is designed based on having a film of oil separating the mechanical contact surfaces within oil film bearings, rolling element bearings and gears. Anything the affects film thickness or film strength such as water content or oil temperature will lead to premature failures. The first place to start, with most rolling mill equipment improvement programs, is with the lubrication system.

The system must deliver lubricating oil to the equipment at a precise flow rate, temperature, and pressure within the defined system conditions. The pressures and temperatures of the system must be monitored on a daily basis at various points in the system including a point directly before the fluid enters the mechanical equipment. The critical conditions of the oil include water content, cleanliness, viscosity, TAN and additive levels. The primary focus for mill maintenance on a daily basis should be in water content and cleanliness, while the other parameters should

be monitored using outside professional laboratories on a monthly basis. Although many oil suppliers will provide this service, the key is to know the prescribed levels for each system and adhere to those levels continuously to maximize the system performance.
The primary contaminant in lubricating oil systems is due to water ingress and with the mill water comes mill scale. Excessive water levels consume those additives in the oil that are intended to enhance water separation and adversely affect the oils ability to maintain film strength. It is essential to establish a program to detect water ingress quickly and eliminate the source. There are many types of lubrication systems in various long rolling mills around the world however; there are some basic measurement techniques that apply universally. They include sampling the supply lube on a daily basis looking closely at the trend data, and looking closely at the oil returning from the equipment using a piping configuration that allows the heavier water to drop out of the return oil flow into a dedicated chamber that can be observed or monitored with electric sensors. This drain line analysis is effective under operating conditions and also has great value testing the system statically for identifying points of water ingress. Each method must be refined to suite the actual conditions in a particular mill.
In addition to paying close attention to the oil being delivered to the equipment, it is critical to monitor oil losses. All systems loose oil through the consumption for air / oil systems, leaking seals, filter changes, breathers and leaks in piping. Typically systems will lose ½-1 full tank of oil per operating year. Losses in excess of this amount should be investigated and targeted for potential cost savings. Knowing and understanding the various system limits and trends is critical to ensure the system is functioning continuously in the desired state to protect the critical rolling mill components.

Vibration Monitoring

The goal of vibration monitoring is to detect any type of mechanical defect or non optimal running conditions during the nucleation stage, thus allowing sufficient time to plan and perform necessary repairs, before damage reaches to higher levels compromising mill production. This can only be achieved with absolute knowledge of the rolling mill equipment, proper technologies/sensor application and advanced signal processing and analysis specific for rolling mill equipment and its variable running conditions.
It is not recommended adapting vibration monitoring program/systems from other industries, such as power generation in which the equipment runs at very constant conditions, even if the industry is considered more critical. A rolling mill is characterized for variable running conditions in speed and load that make vibration monitoring far more complicated and challenging.
The ultimate objective is to help mill operators to find out what is causing the problem, what should be done to fix it properly and how to avoid the same situation in the future.
One analysis tells current absolute situation. Historical trends compiled with equipment rebuild records will inform about relative equipment condition. This information is extremely valuable to predict equipment service life.
All this information and deep knowledge of the equipment allows generation of valuable periodic mill condition reports. These reports will categorize the components that will need to be replaced or repaired, giving priority to those that are

closer to failure and are deemed critical. With this information maintenance task can be efficiently planned preserving the effective operation of the rolling mill.

Case Study Analysis: No-Twist Mill (NTM) Bevel Gear Housing Bearing Damage

This is an illustrative example of bearing failure detection at the nucleation stage and correction, the vibration data was taken from a NTM in a Rolling Mill in North America. One of the findings of the report was matching frequencies with a line shaft thrust bearing indicating the bearing had an inner race defect that could lead to catastrophic equipment failure.

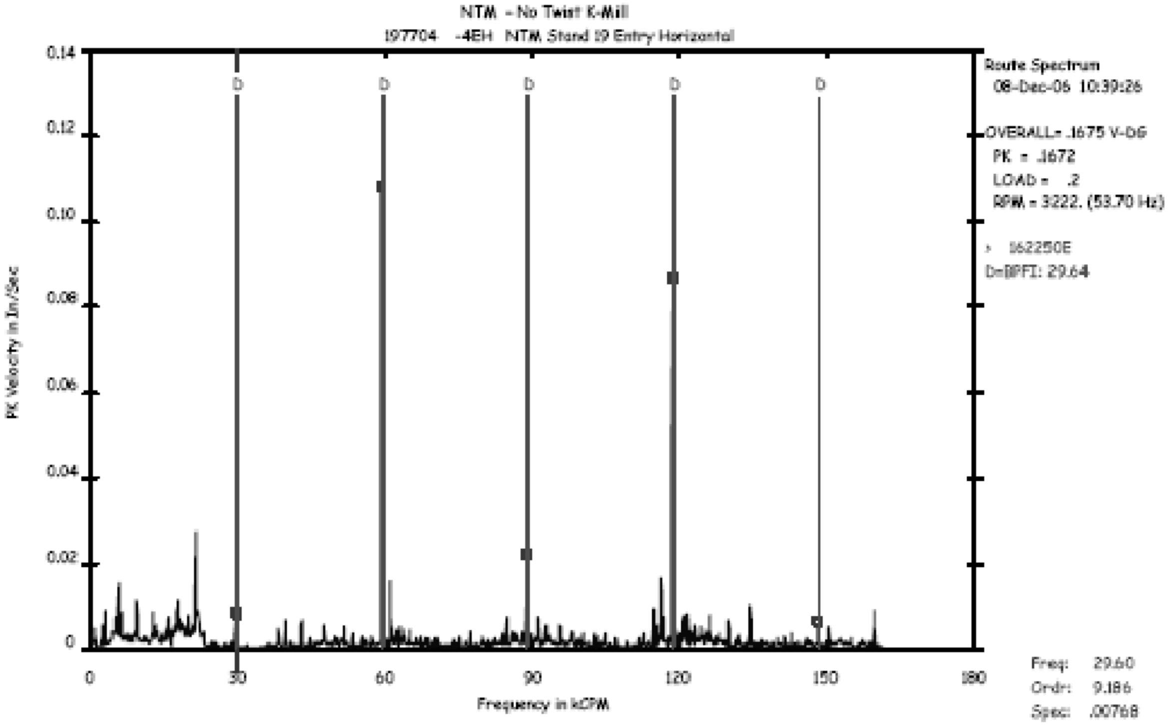

Figure 1. NTM Line Shaft Spectrum. Bearing Failure

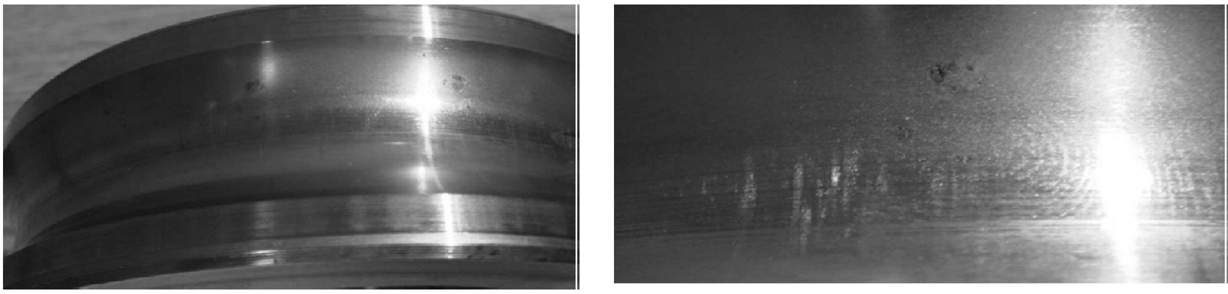

Figure 2. Bearing Inner race Pitting Failure

During rebuild, the inner race of the line shaft thrust bearing was found to have four areas of pitting located in the ball track and spaced equal to the ball pitch spacing of the bearing.
The indications appear to be pitting that was initiated by corrosion. These conditions suggest that the mill sat idle for some period of time with water present in the oil. The contact area between the four balls at the bottom of the bearing and the inner race began to pit due to corrosion caused by the water contact. Continued operation

resulted in propagation of the pitted areas leading to a predicted “failure” of the bearing.
It is apparent from the close up photo of a single pitted area that a larger piece is ready to break out. At some time, depending on mill operating conditions, these areas would progress to deep spalling and cause catastrophic bearing failure.
The significant fact is that in a confirmed case of corrosion pitting, like this one, there is likely to be other bearing locations that are on the same lubricating system that will follow the same path to failure.

Failure Analysis

The final and critical step in a proactive maintenance program is failure analysis. With failure analysis the primary question is; did the component fail due to reaching the end of its normal life or did it fail prematurely? The analysis continues in the case of premature failures to determine the cause of failure. Although any failure can benefit from failure analysis, it is typically reserved for major components that fail catastrophically because the cost of the analysis. The cause is most often related to load and speed combinations that exceed the limits of the equipment or component design. This is common in older equipment that is operating at higher production rates than the original design parameters. Another primary cause is typically a lubrication failure. In most cases, there are multiple failures that occurred in a chain reaction. A reliable source of the sequence of events that lead to the failure and the physical evidence will normally lead to a positive root cause. The prerequisite information includes lube analysis records, vibration reports, rebuild reports and operational data. Trending this data and looking for variations in the trend often lead to the ultimate root cause and call allow for prevention planning.

Maintenance Planning

The time available for mill maintenance is generally planned on a monthly and annual basis around the required production schedules. The best approach must consider predictive maintenance practices, spares stocking philosophy and the knowledge base of the maintenance team. Although the basic approach can be considered similar for all mills, each mill will have an optimum balance based on their unique requirements and budgets. For example, those mills that have limited maintenance time and low tolerance for mill delays will offset these challenges by an extensive spares inventory and world class maintenance practices.
Most equipment builders will provide recommended rebuild cycles for equipment. These are typically conservative but can vary greatly depending on operational and maintenance conditions. The most affective approach is to combine knowledge based maintenance schedules with condition monitoring to optimize the service life of the equipment. Doing so will reduce the total hours of maintenance required as well as avoid break down situations which typically have significantly more expense than doing the same maintenance under a planned project. Lost production and increased reactive expenses drive significantly higher operating costs in comparison to proactive and predictive maintenance techniques.

Repair/Recondition

Rolling mill equipment falls into two categories with respect to scheduling repairs.

1) There is equipment that is part of routine maintenance (roll housings, guides, etc.). These items are being rebuilt on schedule that requires spare assemblies to be on hand and ready to be installed if there are any problems. These items can be removed and replacements installed during a scheduled shutdown period.
2) There are also mechanical assemblies for which it may not be cost effective or reasonable to have a spare assembly sitting off line for some rolling mills. For this equipment it is critical to have accurate information on the condition of the assembly to schedule a rebuild because potential failures could result in long production delays. If the equipment has rolling element bearings and is an important asset in the rolling line it is most likely to be part of a regular monitoring schedule, including vibration monitoring. As previously discussed, condition monitoring can take much of the guesswork out of planning the repair cycle and in most cases will increase the time between repairs. However, a condition monitoring program does not relieve the responsibility of daily preventative maintenance activities.

In addition to any maintenance planning staff still needs to visually inspect all mill areas. Members of the maintenance staff are building there own baseline of all the equipment when they are around it on a daily basis. Hands-on knowledge is important for interpreting the vibration reports. A monthly condition monitoring report is a valuable piece of data to review the status of the drive components but doesn’t mean that the equipment can be forgotten about in between. The combination of this information with the proactive techniques outlined above is important for determining a rebuild timeline.

The message is not to believe that your calendar will protect your most valuable assets from catastrophic failures, since it is difficult to predict the optimal equipment life simply based on a scheduled timeframe. Time in service may be the easiest variable to track but not the only one to consider when constructing a rebuild program for your machinery. While the OEM can develop a recommended service time but this is based on design data, it is very important to monitor the equipment in multiple ways, trend the data and come away with a solid plan to schedule repairs based on what is happening in your facility.

Equipment Upgrades

Engineering for rolling mill equipment is constantly progressing. The steel market and suppliers are demanding that the equipment be able to roll faster, achieve more consistent and better quality and be more reliable. One of the opportunities that should be considered when rebuilding existing equipment is the ability to upgrade to the latest designs. Many of these advancements can be included at relatively low cost because most of the labor is already included during a normal rebuild. It can be very easy to install the latest gear, bearing or seal design, etc. The benefits are obvious.

- Speed / production improvements
- Increased product quality
- Expanded product mix
- Increased reliability
- Ease of maintenance

Review of technological advancements in mill equipment at the time of maintenance rebuild planning can introduce relatively low cost improvements compared to the alternative of complete equipment replacement.

Mill Optimization

As the activities that have been outlined fall into place some of the mindset shifts to maintaining the gains that have been realized and to look forward towards continuous improvements. Training the mill staff, assigning ownership of the measurements and processes and follow up are critical to ensure the benefits are maintainable.
Ownership of the process and results ultimately drives the thought processes into other areas outside of the rolling line into the supporting areas of the mill. The maintenance shops, the roll shop, and the store house are affected because time that was consumed by reactive instead of proactive actions can be focused on improvements in their daily tasks. Improved planning of scheduled shutdown activities allows all areas to have the right spare parts and the right people in place to perform the required tasks.

Summary

Most long rolling mills have all of the data and resources they need at their disposal. All of the key measurements that are logged daily hold the keys to a proactive approach to maximizing the performance of the rolling mill. An effective operation also relies in having a partner with the best experience, technology and service focus.
An effective rolling mill operation is heavily linked to an effective predictive maintenance program that saves far more than it costs:

- Reactive maintenance strategies are not safe, are unpredictable and are not ultimately cost effective
- Preventive maintenance is important but not enough
- Predictive maintenance driving preventive maintenance ensures the best use of financial and human resources

The necessity to utilize these types of activities is more critical than ever before. The ever changing dynamic of the modern steel industry exposes any and all inefficiencies that can be the difference between mill profitability or closure. Siemens VAI LR Services provides all of the necessary tools and, together with detailed equipment and process knowledge, can tailor any improvement plan to maximize mill utilization.