Reliability Achievement Silver Award: Improving Mill Performance Through Roll Shop Process Control

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ABSTRACT

Rolls touch the surface of every product steelmakers produce. It is hard to overestimate the importance of a Roll Shop to a Rolling Mill. Improperly ground rolls lead to problems such as: mill chatter, backup roll (BUR) printing, and product gage variability. The roll quality directly influences finished product quality and production equipment reliability. So, how do you control roll grinding quality? Roll grinding is the act of machining a roll with a grinding wheel. This machining process must be controlled in order to produce acceptable roll quality. Real-time grind feedback and integrated operator screens are essential to the consistent production of high quality rolls.

This paper documents how and why Roll Shop processes impact both Roll Shop and Rolling Mill performance. Problem solving approaches by USS-POSCO Industries (UPI) will be discussed. The paper explains how the solution was developed and what lessons were learned along the way.

THE PROBLEM

UPI's Double Cold Reduction Mill (DCR) had a long history of unscheduled backup roll changes due to printing (Figure 1). In 2005, the DCR was converted to a DUO Mill that runs both single and double reduced products. The impact of unscheduled backup roll (BUR) changes specific to roll printing became more pronounced and represented an important production opportunity. Historical DUO Mill delay and roll service costs due to printed rolls exceeded $300,000 annually.

Printing on BURs resulted in mill chatter, excessive mill noise, speed reductions, shortened roll life, increased mill downtime and quality defects.

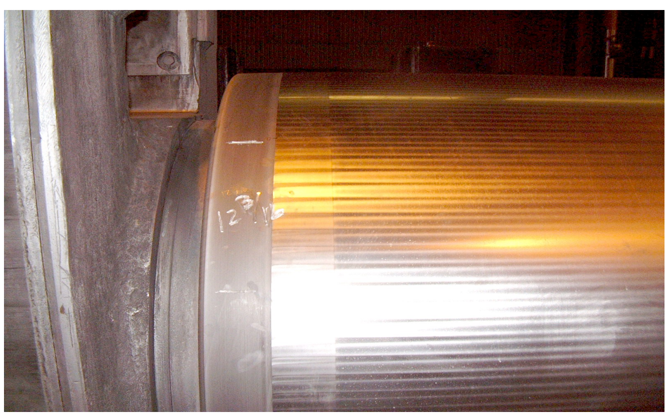

Figure 1. Printed BUR from DUO Mill

Figure 1 shows a printed BUR after a shortened campaign in the mill. Two white lines on the left shoulder of the roll are 12.2" apart and represent the period of 10 printed lines. The period of a single printed line on this roll is 1.22". Spacing of 1" to 1.5" was typical. Although BUR printing has many sources, spectral data indicated damage was the result of a patterned work roll. Historical vibration monitoring at the DUO Mill consistently identified issues originating with the work roll grinding process. Periodic monitoring at the mill was an effective tool but relied on the availability of a vibration technician. It was recognized that a dedicated online monitoring system at the DUO Mill would provide information needed to understand issues causing printed BURs.

INFRASTRUCTURE AND GROUND WORK

An online condition-based monitoring system was installed during the 2005 DUO Mill project. This system allowed UPI to monitor mill vibration in real time. UPI has since developed the automated capability to identify different sources of mill vibration. For example, changes to the grinding headstock speed resulted in a measurable change in the vibration at the mill.
When the DUO Mill upgrade project came on line, product speeds were increased and BUR printing occurrences also increased. Alarm levels to detect printing on BURs were set and vetted by monitoring mill vibration levels and observing the damage to the rolls in the mill. Initial DUO Mill chatter alarms were set to 1 psi. At this level, the operator begins to hear the chatter on the mill. Currently the DUO Mill chatter alarm is set to 0.5 psi. This alarm occurs just before the BUR printing is visible to the operator. If the chatter condition is allowed to continue, it will increase in audible level until it is too loud for the operators to safely tolerate.
Figure 2 shows a typical DUO Mill production week. Blue and gold points on the graph represent Stand 2 Chatter alarm band energy levels. The black dashes on the top of the graph are a work roll percent speed reference. W.L. Roberts states in Flat Processing of Steel, "Simplistic ratios of work-roll-diameter to backup-roll-diameter should be avoided"[1]. "Simplistic" or integer ratios allow surface damage (i.e. grinder pattern) to transfer from the hard surface work roll to softer surface BUR. Though not always a practical solution, avoiding integer ratios mitigates the problem. The triangles at the bottom of the graph represent work roll changes. The colors represent integer (red), non-integer (green) and integer with work roll grinder pattern (black).

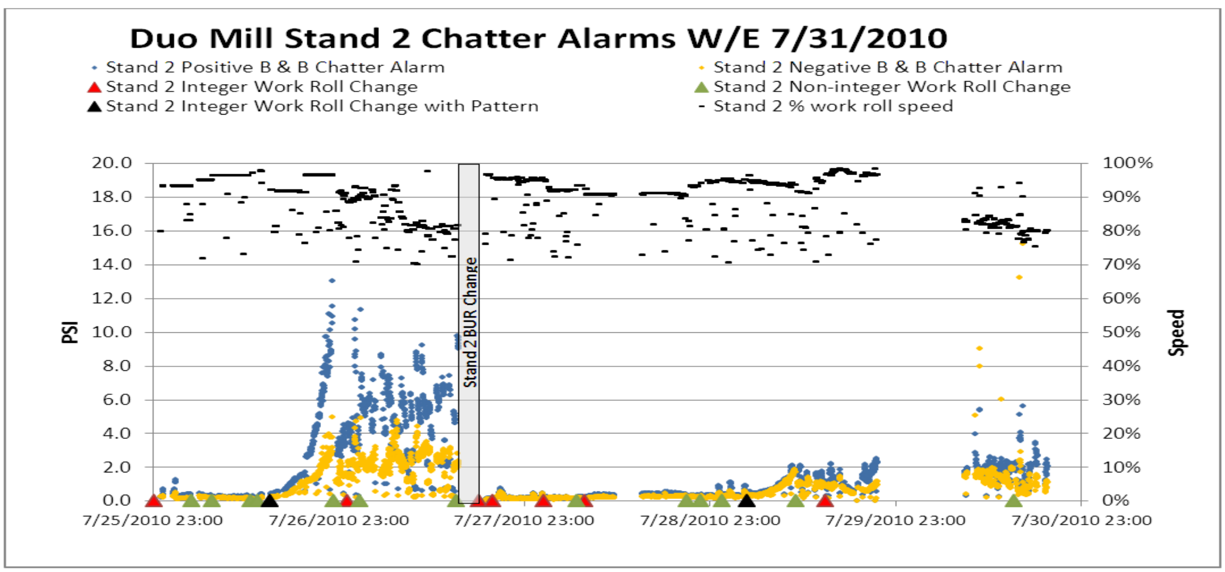

Figure 2. A week of production on the DUO Mill. Psi measured with pressure transducers at the bend and balance blocks

Figure 2 is a scatter plot used by UPI's Applied Reliability Group (ARG) to evaluate mill vibration during a period of production. On 7/26/2010, a set of work rolls that had both integer ratio and grinder pattern were inserted into the mill. This resulted in an energy increase in Stand 2. After a subsequent BUR change on the same day, the vibration level decreased. The unscheduled line stop for BUR change was the result of printed BURs in Stand 2. Another set of integer ratio work rolls with grinder pattern was inserted into Stand 2 on 7/28/2010. This set of rolls began to excite the mill, but was changed before too much damage occurred to the BUR. The gap in data on 7/29/10 is a result of an unscheduled line stop due to unrelated maintenance. The process line work roll speed was slowed during the high vibration period on 7/26/2010. This represents the operators attempting to control BUR damage and quiet the audible noise caused by chatter. Although slowing the mill can be an effective method to control damage, it has a negative effect on productivity.

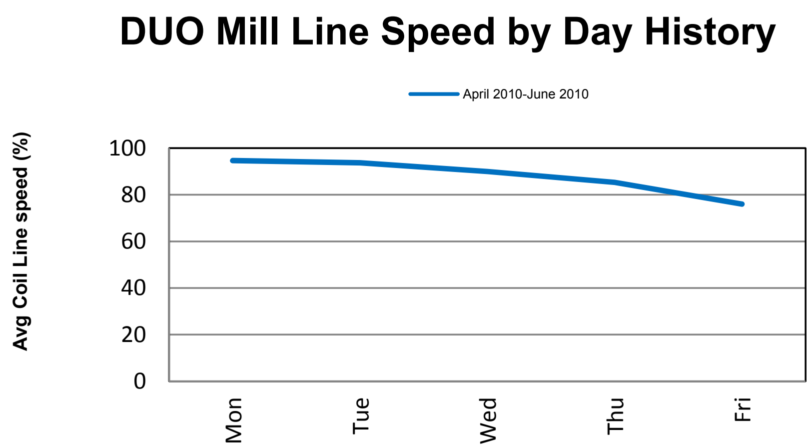

Figure 3. Production chart of weekday average line speed

Figure 3 shows average line speed by day of the week between April 2010 and June 2010. This data was taken prior to the installation of an online monitoring system on the grinder. The DUO Mill began each week running unrestricted line speed. Production slowed each day due to an increase in audible noise. The weekly production lost from slowing down was 7% per week and 20% on Fridays alone. At this point, the value of addressing grinding process problems became evident.

Work roll pattern affects the DUO Mill at a threshold the grinder operator cannot see, hear, or feel. Initial efforts to avoid work rolls with grinder pattern included placing a number of restrictive controls on the roll grinding process. Some of these included:

- Red light alarms were installed to give the operator an indication of excessive grinder carriage vibration.
- Vibration collection routes provided time-based measurements of each grinder's condition.
- Grinder wheel speed Blackout Zones helped the operator avoid natural frequencies of the grinder.
- Grinder headstock speed control limited the potential for a defect to excite the mill.
- Wheel dressing and balancing procedures were instituted to eliminate sources of grinder excitation.
- A data recorder was installed for logging grinder carriage vibration measurements.

Roll Shop grinding practices relied heavily on the experience of the operator and tribal knowledge. Problems were traditionally resolved through trial and error troubleshooting. Operators had limited real-time feedback of key process variables that affect the roll's surface. Quality assurance checks were conducted post grind. Historically, vibration and signal analysis had been effective in identifying grinder problems, but benefits were only realized when an analyst was present. It is impractical to assign a full time analyst to a roll grinder or to turn a grinding machine operator into an analyst. A monitoring system capable of clearly communicating with the operator addresses this dilemma.

TEAM FORMATION

Roll grinding "Best Practices" are required to produce a high quality roll. A monitoring system with a simple operator interface is also required to assure rolls are ground defect free. Simple operator interface means a system that includes real-time operator feedback in a format easily understood by the operator. The output needs to indicate alarm threshold violations and provide guidance on how to respond. The system needs to incorporate a quality control process that assures all rolls are within specification. Grind session data must be logged and attached to the roll for the operating unit to review, and archived for roll history. A partial list of system requirements includes:

- Simple real time operator process data display
- Ability to acquire and archive process data
- Tools for data analysis
- Roll acceptance indication for the grinder operator
- Ability to communicate with grinder control computer
- Customizable screens and alarms

In May of 2010, a project team was assembled to develop a system that would be installed on Grinder #4. This grinder is dedicated to DUO Mill work rolls. The project team was made up of a multi-disciplined group including: Automation, Reliability, Roll Shop Operations, and Electrical Maintenance. The specification was written before considering commercially available options. It quickly became apparent that the system envisioned was not commercially available. Ultimately, a system was selected that provided a good analysis package and open architecture. This allowed UPI and the monitoring system vendor to customize the system for a roll grinder application. A permanent system was installed, commissioned, and activated on Grinder #4 by November of 2010. It included an operator screen with representations of key operating parameters and vetted alarms. Algorithms of critical process measurements were developed to help the operator control the grinding process. An alarm level was established to ensure rolls with excessive vibration would not get released to the mill.

GOING ONLINE

Figure 4 shows vibration levels of grind sessions performed on July 27, 2010 using a preliminary condition monitoring system. Each group of points represents a work roll being ground. While most of the rolls were ground with vibration levels below 0.03 mils peak-peak (p-p), some rolls exceeded 0.06 mils p-p. Rolls with high vibration levels caused excitation in the DUO Mill. A roll's performance in the DUO Mill was found to be directly related to its grind session vibration level. The vibration variation between grind sessions indicated a good grinder can make a bad roll.

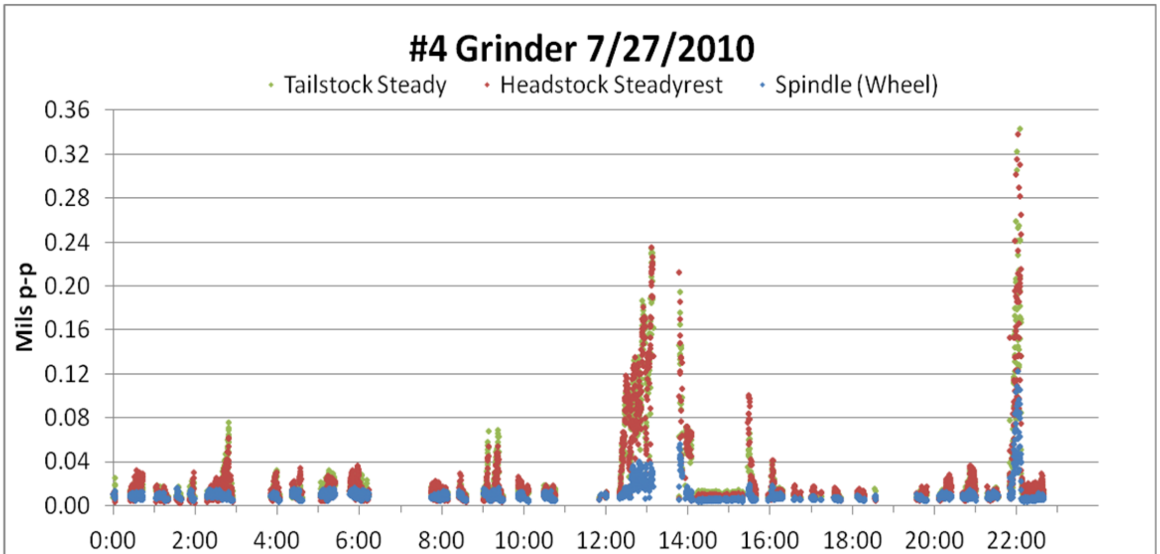

Figure 4. Amplitude of work rolls ground on July 27th 2010.

The roll grinder process control is reliant on the Roll Shop Operator. The operator tries to control the grinding process, but only controls some of the process variables. Table I shows a list of process variables that affect the grinding process. The Grinder Operator needs to understand these variables and how they affect the process.

Process Parameter	**Operator Controlled**	**Not operator controlled**
Wheel speed	X	
Roll speed	X	
Wheel load (percent amperage)	X	X
Traverse speed	X	
Wheel diameter		X
Wheel surface condition	X	
Type of grinding wheel		X
Roll diameter		X
Coolant condition	X	
Coolant flow rate		X
Mechanical/Electrical condition of grinder		X

Table I. Grinder process variables

It is common practice for operators to make parameter changes without fully understanding the impact of the changes. For example, the operator may change how hard the wheel is cutting into the roll. This is referred to as aggressiveness, an index based on maximum chip thickness. If the wheel is pushed too much or too little, it may create grinder chatter. The wheel cutting load will also affect the roll's finish. There is a window the grinding wheel is designed to operate within to avoid chatter. Typically, the operator does not have sufficient information to recognize if there is a problem during the grind session. If a problem is recognized, they don't have an effective tool to determine the appropriate process change. Therefore, operators resort to trial and error troubleshooting. These experiences contribute to the tribal knowledge of the process control and problem-solving strategies.

The grinding wheel is an example of a process variable the operator only partially controls. The operator can choose how fast to run the wheel and to an extent the load, but has no control of the wheel diameter. Therefore, a set of grinding parameters that worked with a 32" wheel may not work with a 30" or 28" wheel and vice versa. The operator requires a tool to be able to see the effect of all system parameters on the work roll and how process changes affect their product.

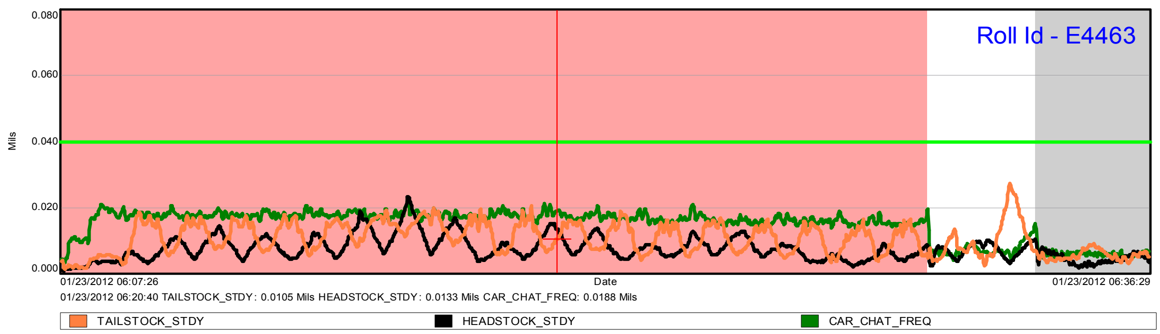

Figure 5. Grind process in control

Figure 5 is an example of a grinding process in control. Phases of the grind cycle are represented by; roughing (red), semi finish (white), and finish (grey). Process parameters were not changed during the roughing cycle. The movement during the roughing cycle is about 0.02 mil p-p at all three probe locations.

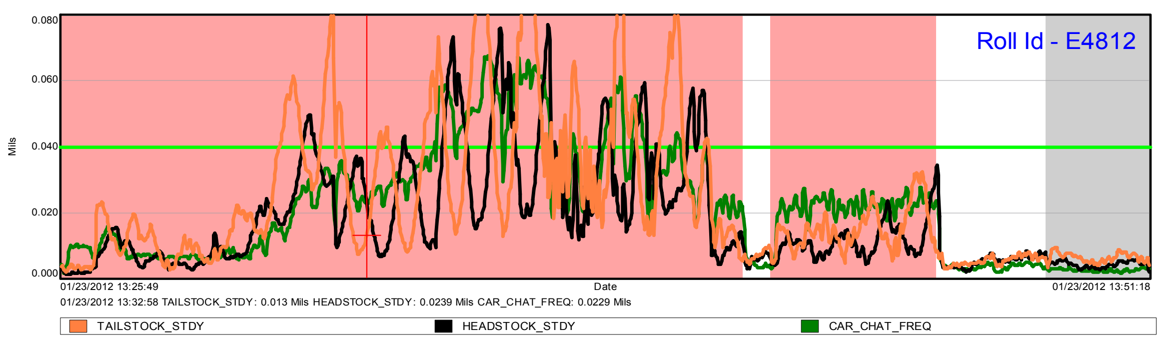

Figure 6. Grind process out of control

Figure 6 is an example of an out of control grind process. The operator makes several changes throughout the roughing process attempting to get the grinder back in a stable condition. After changing grind process parameters, the roughing cycle was restarted and the roll was ground within alarm limits. Figure 5 and Figure 6 represent grinds on two consecutive rolls and show how critical the grind parameters are to controlling the process. Table II contains a list of the initial process parameters for the three roughing cycles. After grinding a chatter free roll, the operator reduced the wheel speed by 31.6% and reduced the headstock speed by 11.3%. The aggressiveness was also increased by raising the wheel load and traverse rate. During the out of control roughing cycle, the operator made multiple trial adjustments to the grinding parameters. Ultimately, the settings returned to similar levels that were successful on the previous roll. The Aggressiveness Index is used to show the effect of operator changes to multiple variables.

Initial Process Parameter	Figure 5	Figure 6 1st roughing cycle	Figure 6 2nd roughing cycle
Wheel speed	976	667	903
Roll speed	44	39	44
Wheel load	17.5	18.3	18.3
Traverse speed	80	90	90
Wheel diameter	27	27	27
Roll diameter	20.25	20.44	20.44
Aggressiveness	120	170	140
Mechanical/Electrical condition of grinder	No changes	No changes	No changes

Table II. Process Parameters on Grinder #4 representing figure 5 and figure 6

Figure 6 shows that the operator can make the proper changes during a grind. Given the proper tools, a problem can be corrected before a grind cycle is completed. An in-process control minimizes regrinds and assures that a roll is good before leaving the machine.

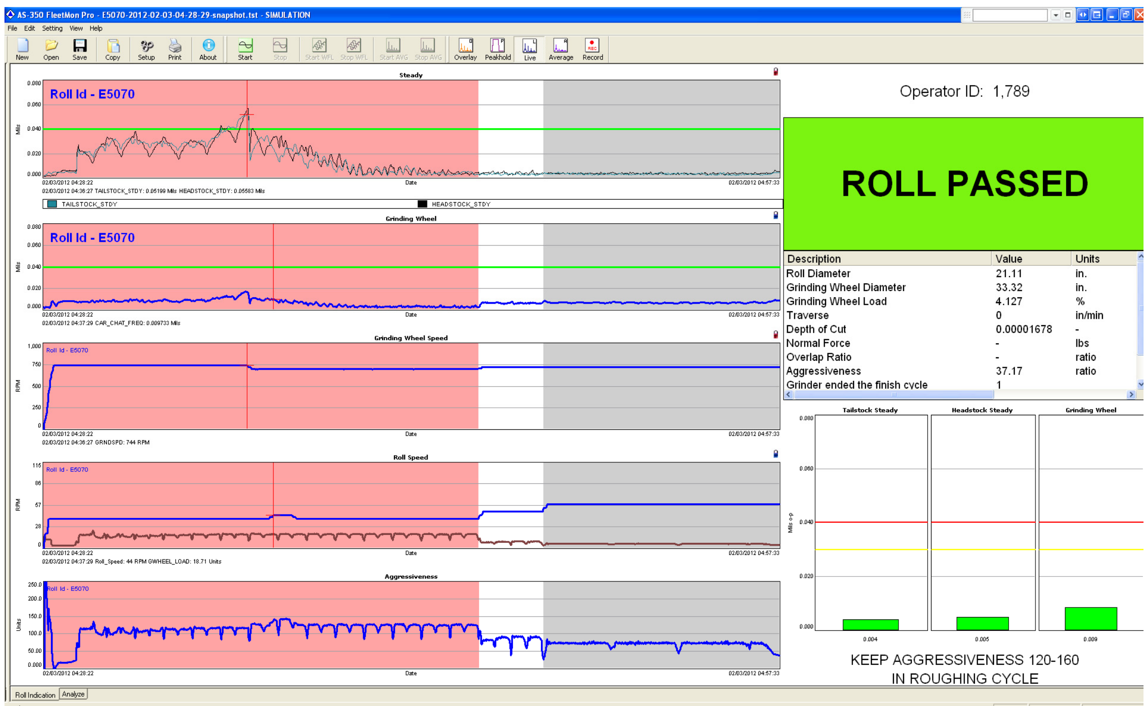

Figure 7. Complete work roll grind cycle

Figure 7 is a screen shot created during the grind session. It is printed at the completion of each grind and shipped to the mill with the roll. The operator uses information from this screen to make informed decisions during the grinding process. The top graph monitors the horizontal movement of headstock and tailstock steadyrests. The second graph displays the horizontal carriage movement. Green lines on these graphs indicate the grind vibration alarm level is set to 0.04 mils p-p (0.00004”). The third graph shows the grinding wheel speed (rpm). The fourth graph displays the roll speed (rpm) and the wheel percent load. The bottom graph shows the Aggressiveness Index. The Phases of the grind cycle are indicated by colors.

Operators are instructed to keep the Aggressiveness between 120 and 160 to maintain the wheel cutting surface. In Figure 7, the operator noticed that the Aggressiveness Index was at 100 and needed to be increased. The operator decreased the wheel speed and increased the headstock speed to raise the aggressiveness to 140. This correction caused the dull wheel to sharpen itself by breaking down.

The screen in Figure 7 has the operator ID at the top and an explicit Pass/Fail indication based on Boolean logic. The bar graphs in the lower right corner show the instantaneous vibration feedback from the carriage and both steadyrests.

The table on the right side of the screen helps the operator to better understand and control the vibration in the rolls being ground. The operator already had access to some of the grind parameters but the new screen provided one location to quickly reference information such as:

- Grinding wheel speed
- Traverse speed
- Roll Speed
- Wheel diameter
- Roll diameter
- Wheel load

To better understand the effect operator settings have on the rolls, other process parameters were developed and provided to the operator:

- Normal force – The contact force between the grinding wheel and the roll.
- Overlap ratio- A ratio of the roll rpm and the traverse rate indicating how much the grinding wheel is overlapping the previous grinding pass.
- Aggressiveness – An index that indicates the grit penetration depth. This is used to determine grinding wheel brake down and roll surface finish.
- Depth of cut- The amount of material removed per grinding pass.

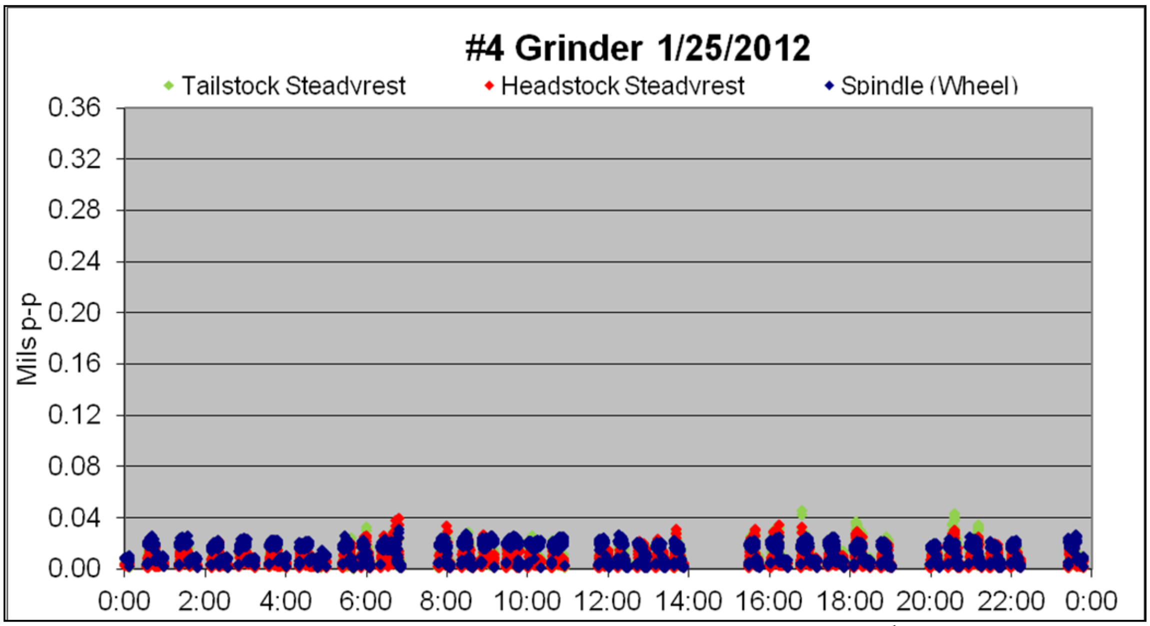

Figure 8. Amplitude of several work rolls being ground on January 25th 2012

Figure 8 shows operators in control of the roll grinding process. They are able to set parameters within their control to compensate for parameters that are outside their control. The vibration variation between grind sessions is much lower. This is the result of a tool that enabled operators to make informed decisions and take actions to produce a quality roll.

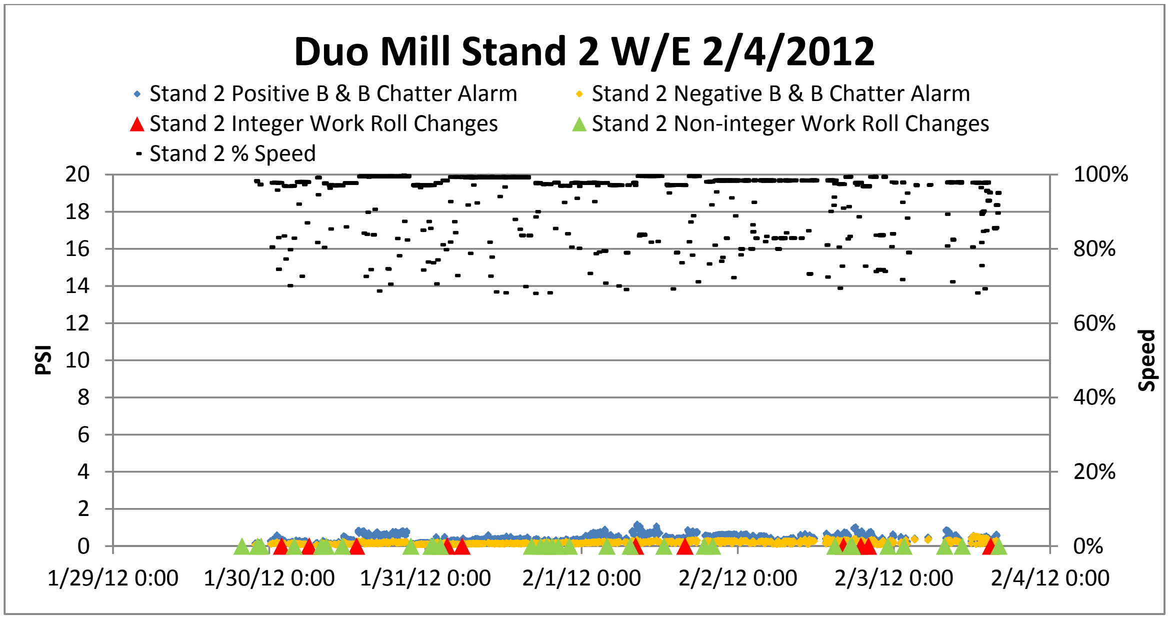

Figure 9. A week of production on the DUO Mill. Psi measured with pressure transducers at the bend and balance blocks

Controlling the grinding process is only beneficial if there is a measurable improvement to the mill. A recent DUO Mill production week is shown in Figure 9. Blue and gold points on the graph represent energy in the Stand 2 chatter alarm band. The triangles at the bottom of the graph represent integer (red) and non-integer (green) work roll changes. The graph shows the impact of controlling the roll grinding process on the Duo Mill. Controlling the roll shop process insured patterned rolls are no longer sent to the mill. The Duo Mill has not had an unscheduled BUR change for work roll induced pattern since a grinder alarm level was initiated November 2010. The black dashes on top of Figure 9 show percent line speed for the week of February 4, 2012. The operation is consistent throughout the week and does not avoid speeds or reduce production to quiet the mill. This has resulted in a cost savings from productivity improvements, grind time and material removal of the BURs. Productivity improvements include; less down time, and higher turn rates resulting in higher production capabilities.

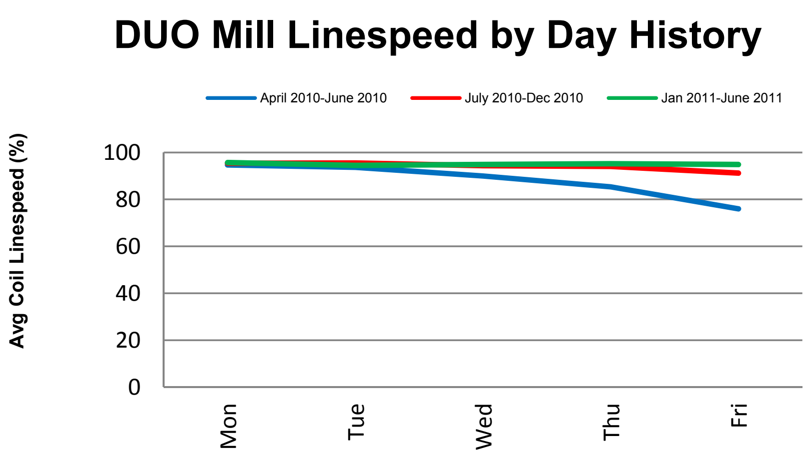

Figure 10. Duo Mill average line speed by day of the week

Figure 10 shows the average daily line speeds from April 2010 thru June 2011. The blue line represents the average line speeds from April 2010 thru June 2010. This is prior to the system being commissioned on Grinder #4. The DUO Mill began each week running unrestricted line speed. Production slowed each day due to an increase in audible noise. The weekly production lost from slowing down was 7% per week and 20% on Fridays alone.

In July 2010 the first real time condition monitoring system was active on Grinder #4. The red line represents the average daily line speeds from July 2010 thru December 2010. It shows how the DUO Mill productivity reacted to the Roll Shop Operator’s ability to see vibration levels during grind cycles. This initial system was made up of velometers on each steadyrest and on the Carriage.

Reference tachometers indicated rotational speed of the grinding wheel and roll. Although the operators started with no alarm limits, they were instructed to play with parameters and watch how the vibration reacted. After a couple of weeks a threshold was added to the screens and the operators were instructed to stay under it. During this period of time it was determined that our grinder could perform at a level below 0.04 mils. This vibration level eliminated the DUO Mill chatter excitation.
The green line shows average daily line speeds at the DUO Mill from January 2011 thru June 2011. In November 2010 alarms were added to the operator screens and rolls that did not meet alarm requirements were reground. Alarms were instituted so that the operator could see the alarm on the screen during a grind. To close the loop with DUO Mill Operations a printout of the grind cycle was included with each roll sent to the mill. This allowed DUO Mill Operators to know the quality of the rolls going into the mill.

Rolls touch the surface of every product steelmakers produce. The importance of a roll shop to a rolling mill is often over looked. When a roll shop is given the proper tools they become empowered to control the grinding process and produce quality rolls. Improperly ground rolls lead to:

- Mill chatter
- BUR printing
- Gage variation
- Poor product quality and finish
- Equipment reliability issues

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By controlling the grind process the Roll Shop produces pattern free rolls. When rolls are free of grind pattern mill productivity improves. The Duo Mill realized a production gain of 7 percent through avoidance of running off speed. The impact of unscheduled BUR changes specific to work roll printing has been eliminated. The payback on this project was less than 2 months and continues to save UPI well over $300,000 annually.

REFERENCES

1. William L. Roberts,"*Flat Processing of Steel*" Marcel Dekker, INC., 270 Madison Avenue, New York, New York, 1988, pp.663