Automated Coil Trimming System for Wire Rod Mills in the Digital Era

One requirement in wire rod production is head and tail coil trimming to remove rings with property variations. In-line shears prior to coiling at the laying head are available, but are difficult to operate and maintain. Most mills rely on manual trimming at a coil inspection station — a labor-intensive and potentially dangerous task. A new system has been developed for trimming within coil handling. A vision-assisted robot equipped with a ring separator and trimmer identifies, trims and removes unwanted rings. The new system’s capabilities are presented with results from a pilot facility and an operating wire rod mill.

One of the most important aspects of product quality in a long rolling mill that produces coiled rod is the final material properties of the coil. Due to the quenching method utilized and the varying density of the head and tail of the coil processed on the cooling conveyor, the rolling process itself produces wire with differing properties at the head and tail of each coil. Coil quality features include the orderliness of the rings within the coil, uniformity of the inner and outer diameters, compactness of the coil package for efficient shipment and subsequent payoff in downstream user operations, and consistent tensile values throughout the coil. While advancements in quenching technology have reduced the number of head and tail rings that may not have conforming tensile values and metallurgical properties, long rolling mills still produce them and require their removal before further processing of the as-rolled rod. Coils that have not been trimmed optimally are one of the principal factors of poor-quality coils. When coils have not had enough material removed, the metallurgical properties of the head and tail of the coil vary from the main body of the coil. Alternatively, coils that have had too many rings removed impact the mill’s process yield. This paper describes a new patent-pending approach to improve this coil trimming challenge.

Discussion

Need to Trim Coil Ends — In the hot working of metals, the method and rate of heat removal have varying but well-understood effects on the final mechanical properties. After metal billets roll to a required size in a wire rod mill, a series of water boxes quench the rod, which is then coiled and air-cooled on a conveyor. The required metallurgical properties dictate the number and location of water boxes and air-cooling zones. Owing to process limitations, the water boxes cannot cool the front and tail ends of the rod efficiently. Coil end rings also cool faster compared to the rest of the coil as it moves on the cooling conveyor. As a result, the ends of coiled rod possess inconsistent mechanical properties compared to the body of the coil. These differences in metallurgical properties present as low surface quality for certain grades of steel being rolled, as shown in Fig. 1. Such low surface quality is sometimes referred to as “bubble scale.”
In addition, the presence of tension/compression in the mill during rolling can mean front and tail ends are usually out of size tolerance. Though advances in water box and tension control systems have greatly reduced the quantity of coil ends that need trimming, the process of trimming coils is still considered necessary. In order to deliver quality product to end customers and also meet internal and industry standards, a typical rolling mill would trim and scrap these coil end rings before shipping to customers.

The trimming operation needs to be located after the end of quenching and air-cooling to ensure metallurgical properties are well-established, and surface defects can be easily identified. Trimming less material than is required leads to quality issues, whereas trimming more material results in yield loss. Hence, the accuracy of the trimming process is important to sustain optimal lengths of trimmed coil ends.

Current State of the Art — There are currently two approaches to trimming the coil in a wire rod mill. The first is the use of high-speed trim shears, generally positioned before the laying head and after quenching, as shown in Fig. 2. The shears, as shown in Fig. 3, automatically trim the head and tail of each billet rolled in the mill within setpoints defined by the operator or by an algorithm defined by the quenching process utilized for a particular heat of material. Accurate and repeatable trimming of rod with a speed in excess of 120 m/second can be challenging and requires a high-tech, high-maintenance solution with constant attention to detail for sustained operation. Irrespective of the difficulties to maintain the shear’s constant operation, however, the fact is that coil trimming occurs before the production of the material’s final metallurgical properties on the cooling conveyor. Therefore, at some later process stage, additional trimming may be necessary. For those plants that seek a lower-cost, less maintenance-intensive process, the second state-of-the-art method utilized is the manual trimming operation, generally carried out downstream in the coil handling area at a dedicated trimming station or location, as shown in Fig. 4. This is a mundane, repetitive task that can lead to strain injuries and lack of attention to detail, resulting in mistakes when operators remove too much or too little material from each coil. Safety is a further issue in this regard since workers who are not paying attention or are too comfortable with the process can sustain hand injuries, burns from hot coils and/or injuries from the cutting tools used to trim the wire rod.

Manual Trimming Process Study: Steel rod mills have been using a manual process to efficiently trim the coil ends for many years. The process has gone through several iterations and has been optimized. Though there are minor variations in this process from mill to mill, it remains similar at a high level. A study of the manual trimming process in a rod mill on several sizes and grades has led to the identification of a nine-step process, as shown in Fig. 5. A hook or a mandrel brings a coil to a designated trimming station, where an operator is ready with a hydraulic cutter hanging on a balancer.
When the coil stops, the operator quickly locates the front end of the coil and grabs the first few rings by hand. The operator then pulls these rings toward the open end of the hook/mandrel to spread the rings apart. At this point, the operator is in a better position to count the number of spread rings. A larger separation is created at the approximate number of rings to be cut. The operator then maneuvers the hydraulic cutter to position this ring into the cutter between the blades, triggers the hydraulic cutter and cuts the particular ring. After the cut, the operator moves their hand around the circumference of ring to make sure the coil is clearly divided without any interlacing of rings. Additional processing is needed if there are interlacing or buried front ends. If there are no interlacing or buried front ends in the coil, the operator grabs the pack of scrap rings by hand and carries them over to a scrap carrier located nearby. Many times, they carry the pack of scrap rings on their shoulders due to the weight of the rings.

The tail ends can be trimmed at the same location and then the coil transferred to a structure to remove the scrap rings. Alternatively, the coil can be transferred to a structure located in a second trimming station. The tail ends can then be trimmed at this second trimming station, following the same procedure described earlier. The choice depends on time available between coils. Ideally, an automatic coil end trimming system should follow a similar procedure. It should be noted that the coil could be hot to touch when it reaches the trimming station. Trimming the tail ends of a coil in a similar process presents additional worker safety issues.

The Automatic Trimming System — When developing a robust, repeatable solution to the challenges associated with accurate material removal from wire rod coils, it was paramount to preserve the quality of the finished product. This meant that whatever method of material removal would be employed, it must take place after the cooling conveyor and determination of the material’s final metallurgical properties.

In order to trim the correct amount of material from the head and tail of each wire coil produced, a system would be needed that could detect and count individual rings of the coil, move to a defined position, cut the coil, and remove the waste in a safe, efficient and repeatable fashion. Given the recent developments driven by digitalization, vision systems and automated functions, it is possible with the correct process to link a vision system directly to an automated function to accurately distribute, count, cut and discard waste material, with a repeatable accuracy that far exceeds an operator’s ability or the ability of a high-speed shear.

System Components: The patent-pending coil end trimming system (TrimRob) consists of two vision-guided robots, one for each end of a coil. The coil handling area before the coil compactors, where manual trimming operations are typically stationed, is an ideal location for such a system. A typical TrimRob system layout is shown in Fig. 6. The layout needs to be custom designed for a mill, depending upon the type of coil handling system, coil transfer system for tail end trim and the available floor area.

Vision System: At the heart of TrimRob is the vision system. It...
consists of cameras with an associated vision process software. The cameras can be mounted on an independent stand, as shown in Fig. 6, or on an existing coil handling structure. They are enclosed in a special climate-controlled box to protect from heat, scale and dust. Two cameras are mounted a set distance apart to cover an overlapping field of view. The coordinate systems of the cameras and the robots are tied together through a calibration process. The vision process is designed to count rings starting from the end of the coil and output the \((x,y)\) coordinates of the desired number of rings to be cut. The vision system hardware can be stand-alone or built into the robot controller. The cameras take snapshots of the coil at various points.

**TrimRob Work Cell:** The robotic work cell is designed according to the industry standard ANSI/RIA 15.06-2012. All components of the system are enclosed in an 8-foot-tall, see-through mesh guard fence, as shown in Fig. 6. Safe distances from the robot and moving parts are maintained according to the standard. Movement of a coil in and out of a work cell is controlled through smart safety light curtains. Specific areas within range of the light curtains are muted for the coil to pass through, at the same time sensing entry of operators into the work cell. The robot goes to a safe position or stops instantly, depending on the type of trigger. Access gates are provided with a pushbutton access, allowing the operators to enter the work cell safely for maintenance or other reasons.

- **Robot arm and controller** — Six-axis industrial robot arms are used for trimming, as shown in Fig. 7. The maximum payload of these robots exceeds the weight of the end effector and force required to spread the rings. The range of motion is mechanically locked for added safety to avoid accidental movement outside the required area. The hydraulic pump system can be mounted on the axis 1 casing and hoses routed through a dress pack to the end effector. The hydraulic valve and control system along with the dress pack can be mounted on the axis

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**Figure 6**

*Automatic trimming robotic work cell typical layout.*
3 arm and/or casing of the robot mechanical unit. Each robot has an individual controller unit and a handheld teaching pendant. Cables from the robot mechanical unit, vision system, human-machine interface (HMI) and teach pendant are plugged into the robot controller. These cables can be routed through a trench or a walkable cable tray to avoid tripping hazards. The controller is located outside the guard fencing and next to an access gate.

- Coil transfer for tail end trim — Regardless of a vertical or horizontal coil handling system, the coil needs to be transferred to an intermediary holding structure to trim tail ends. Fig. 6 shows a coil transfer hook installed in a pit for a horizontal coil handling system. Other types of coil transfer systems can also be integrated into the work cell, as per the mill’s requirement. The safety light curtains are muted for the coil transfer to pass through during a trimming cycle.

- Scrap removal system — The robots trim a specific number of rings from both ends of coils depending on the size, grade and customer requirements. These trimmed scrap rings need to be removed from the work cell at regular intervals. The turntable scrap removal system shown in Fig. 6 is one among several options. Three scrap carriers are placed on the turntable at a 120° angle, separated by guard fencing.

The front-end and tail-end robots can independently deposit scrap on the carriers, while a forklift replaces them at the same time. A low-height swing gate next to the turntable allows a forklift to replace the scrap carriers without interfering with operation of the TrimRob. This scrap removal system, as designed, seems to be most efficient in terms of timing sequence requirements.

- End effector tool — The trimming end effector tool (TrimTool) is mounted on the wrist of the robot mechanical unit, as shown in Fig. 7. It consists of a cutting head, a pinch roll assembly for sample cuts and an arm clamp for holding the scrap rings. All actuation functions are driven by hydraulics. The design is optimized to keep weight to a minimum, while isolating reaction forces away from the robot’s wrist. The replaceable cutting blades can trim rod products up to 28 mm diameter. The TrimTool is universal, making it possible to use the same design for both front- and tail-end trimming, which simplifies spares.

- Sample collection system — Rod mills typically test physical and mechanical properties of their product at regular intervals to meet quality requirements. TrimRob automates sample collection along with trimming. Fig. 6 shows a sample chute, which is essentially a slide with one end extending into the work cell, while the other end is bolted down to the floor outside the work cell. The length of samples to be collected dictates the angle and width of the sample chute.

- Human-machine interface — The system has a customized HMI that acts as a bridge and ties together the mill coil handling, coil transfer, scrap removal, robots, hydraulic and safety systems. The HMI has the master program that governs operation of entire TrimRob system. It also has a safety programmable logic controller (PLC) that monitors and activates the safety-related features.

Installation — Whether the coil orientation in the system is horizontal or vertical, the system can be easily retrofitted within the confines of an existing coil handling system with minimal impact to the existing equipment and process cycle. The robot mechanical unit is mounted to a baseplate that can be installed on the existing concrete floor using expansion bolts. Turntables, scrap chute and safety fencing can also be installed directly using expansion bolts. The system is designed to minimize civil foundation work. Walkable cable trays instead of trenches eliminate the need for excavation.
TrimRob Process — Although the process of automated trimming is flexible and may vary from mill to mill, a typical TrimRob process is detailed in this section. Obtaining information on the number of rings to be trimmed is the first step in the process. There are four possible means of communicating this information to the HMI:

1. Manually enter the number of rings to be trimmed for a particular run.
2. Send that information to the HMI through the mill PLC by calculating the time taken for water boxes to turn on after the rod entered. This time measurement can determine the length of the rod and, in effect, the number of rings to be trimmed.
3. Count rings that were not cooled according to specifications when they are laid down on the cooling conveyor. A vision camera mounted on top of the conveyor can identify the color difference between uncooled and cooled rings and count the uncooled rings. This information can be relayed via Ethernet.
4. The ideal method is to use a vision camera mounted directly on the robot to identify the difference in surface quality of cooled and uncooled rings. However, this method might not be suited for all grades of steel being produced.

At the beginning of the trimming process, the robot is in the home position, having completed the previous trim cycle. Once a new coil enters the work cell, a proximity sensor mounted on the coil handling structure indicates that the hook is in position for trim. This triggers the vision camera to take a snapshot that can identify the end ring of the coil. Fig. 8 shows a snapshot from a typical line locator vision process. As can be seen, each line closely represents a ring. The robot maneuvers to penetrate the coil with the cutting head. The TrimTool moves toward the open end of the hook to spread the rings. The vision camera takes a snapshot and locates the ring to be cut based on information from the HMI. After positioning and penetrating the coil next to the ring to be trimmed, the latter is guided into the cutting chamber.

After the specific ring is cut by firing the main cylinder, the clamp closes to grab all scrap rings. The robot maneuvers to remove the scrap rings from the hook and carries them over to the sample chute. While the robot is in motion, the sample pinch roll rotates to pull through a pre-determined length of the rod. The main hydraulic cylinder fires for the second time to cut the sample rod length. The cut sample slides down the chute and collects at the base outside the work cell for an operator to pick up. The robot maneuvers to the scrap handling system and drops the scrap rings on a
carrier. The robot then returns to the home position, ready for the next trimming cycle. The entire duration of one trim cycle is approximately 45 seconds, which is close to the time a typical steel mill takes to produce a coil.

All system actions and functionalities are fully automatic and require no human interaction. The vision system is configured to recognize interlaced rings during the ring spreading process. There is a pre-defined process carried out by the robot using the end effector to remove them. There is also a process to overcome buried front and tail end rings that can occur during coil formation and handling.

Proof of Concept — Primetals Technologies USA LLC commissioned a fully operational robotic test bench at its Worcester, Mass., USA, facility. Steel mill conditions were closely replicated for accurate and reproducible results. The test bench consists of a vision-guided robot mounted on an adjustable base. Several kinds of cameras, mounts and lightings were available for testing various applications. Extensive testing and end effector prototyping resulted in a fully automated, repeatable and accurate trimming process.

Conclusions

There is a viable alternative to the current high-speed shear systems for automated trimming of wire rod coils. The system is less intrusive, less maintenance- and process-intensive, and utilizes state-of-the-art equipment that is well proven in other industries, including foundries and steelmaking. The system is self-contained, accurate and repeatable, and provides the best quality final wire rod with its location after final metallurgical properties are defined. More importantly, for those mills that cannot fit a high-speed shear or have doubts about its use, there is now an alternative solution that removes the need for operators to work within a congested, hazardous area.

Reference


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