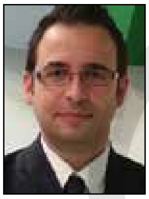
Autonomous Trimming and Sampling of Wire Rod Coil Head and Tail

Digital technologies are transforming industry at all levels. Steel has the opportunity to lead all heavy industries as an early adopter of specific digital technologies to improve our sustainability and competitiveness. This column is part of AIST's strategy to become the epicenter for steel's digital transformation, by providing a variety of platforms to showcase and disseminate Industry 4.0 knowledge specific for steel manufacturing, from big-picture concepts to specific processes.



Authors

Jens P. Nylander (left)
R&D Engineer, AIC Automazioni Industriali Capitanio, Odolo (Brescia), Italy
jens.nylander@aicnet.it

Antonio Ambra (right)
Managing Director, AIC North America Corp., New York, N.Y., USA
antonio.ambra@aicnet.it

This paper presents a novel, patent-pending, autonomous trimming and sampling station, which has been introduced on the market as the TRIMBOT.

Conventional trimming and sampling stations are typically located within the confines of the coil-handling system. It is predominantly a manual activity where at least one operator identifies, separates, cuts and removes anything ranging from a short piece of a ring to several rings from the exposed end of a wire rod coil. This manual activity offers a very poor work environment and is a frequent source of different types of injury for operators. There is also a negative impact to both yield and product quality as individual operators may interpret and implement trimming instruction differently than their coworkers. The manual activity described here is also expensive to operate, without adding any particular value to the finished product. When summarizing the total cost of the labor, and the cost associated with a reduction in yield, together with increased scrap and the negative impact on quality, the total cost is significant.

The system presented in this paper introduces a new process, designed to circumvent many challenges associated with conventional coil trimming by transforming the manual workstation into a completely autonomous trimming and sampling station. Introducing a novel process and bringing it to market has its challenges; any new solution must not only outperform the conventional alternative, but it needs to be justifiable for both total cost and running costs. To satisfy these expectations, the system presented is, from the very beginning, designed giving the right importance to the final total cost.

Albeit the primary purpose of the new system is to eliminate human operations from the trimming procedures, the new process also brings completely new abilities to the trimming station, such as, for instance, dynamic trimming. Dynamic trimming makes it possible to adjust the trimming position in real time to minimize the quantity of material trimmed from one coil in response to changes in the rolling process.

Discussion

Background — In a modern long product rolling mill there are no humans actively working the equipment during production; instead, operators are supervising the process from control rooms at a safe distance from any dangerous equipment. The only time people are allowed near the rolling equipment is during maintenance, repair, or when equipment is removed, replaced or adjusted. This has allowed the process and the technology to evolve and a modern long product rolling mill produces a higher-quality product at a higher production rate with a higher yield, using fewer people while offering a safer workplace.

The story is quite different once the rings are formed into a coil and it enters the coil handling and packaging area. In this area of the long product rolling mill, the process often requires humans to actively work on the rolled product.

As a result of people actively working intensively within the coil-handling system, there are more frequent injuries, such as lacerations, burns and crushed limbs. By relying on human operators to actively participate in the process, there is also the exposure to mistakes, which always result in increased cost.

In a modern coil-handling system, manual activities normally include:

- Collection of a sample for upset test.
- Coil shape inspections.
- Head and tail trimming.
- Collection of sample wire for analysis.
- Application of printed tag to the coil.

In recent years, a robotic tagging application has been introduced on the market and is gaining popularity, leaving coil inspection and trimming as the predominant manual activity in the area.

This is not for lack of trying. Decades ago, the high-speed trimming shear (HSS) was introduced, and under defined conditions and on certain steel grades, it is quite a successful solution. For the most part, however, because it is typically located before the formation of the final metallurgical properties of the wire, it can only do part of the job, and the manual inspection, trimming and sampling station must often remain to finish the job.

There have also been attempts to trim in the coil-forming chamber, and even if a working solution were to exist, it would most probably need a manual inspection, trimming and sampling station to complete the activity as well.

There have been several attempts to develop semi-automatic and fully automatic solutions to replace the human operator at the trimming station, performing some, or all, of the human activities by more or less elaborate technical solutions.

Common Practices — Ring counting is the dominating method of selecting and separating wire to be trimmed and removed from a coil. The reason for its popularity is that it's the most practical method for a human to manage the process in a reasonably safe and accurate way.

Manual trimming and sampling is normally conducted on the exposed end of the wire rod coil as it is presented to the operator supported by either a C-hook or a tilted vertical stem pallet. The process involves several steps that aim to separate the forwardmost rings from the coil followed by counting the desired number of rings plus one or two extra loops just to be on the safe side before making the cut. The cut rings are then removed by the operator and placed into a scrap container. If a sample is required, the operator can quickly cut a sample wire from the trimmed coil before the C-hook is released.

The defining activity in this process is the actual counting of rings, and the trimming process can therefore be referred to as a "ring counting process." Various tools and equipment have been developed over the years to make this work less cumbersome and hazardous to the operator. However, the basic ring counting process is the same.

A New Process — Any trimming method based on the ring counting process has inherent problems with precision and uniformity.

Rather than calculating an approximate number of rings on a C-hook or a tilted pallet, and cutting at an approximate location along the selected loop, a more accurate method would involve actually measuring the distance along the wire, taking into consideration the information already available from actual production parameters in the rolling mill.

Before it is possible to measure the distance with some level of accuracy, the actual end of the wire must be located. When this happens, the process must be able to measure along the wire and reach the exact position where the lesser quality ends and where the prime quality product begins.

Once the exact position is reached, the system must also be able to cut the wire at this exact position, wherever this happens to be along the length of the wire.

Any optimal trimming process must therefore include the following steps:

- Locate the end of the wire.
- Measure from the located end of the wire to the exact position along the wire to make the cut.
- Make a cut at the exact location.

Figure 1

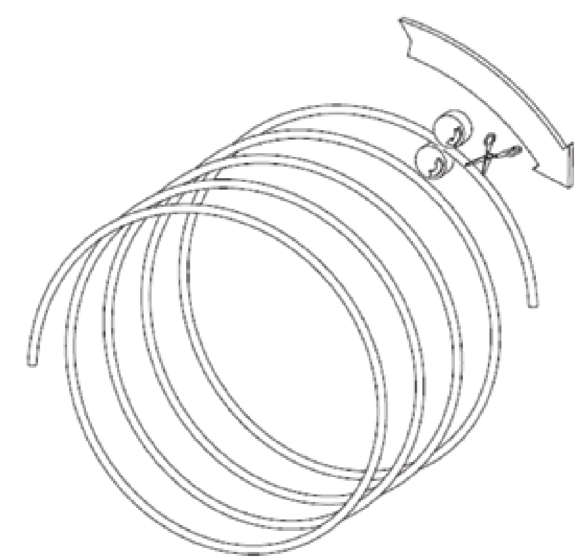


Illustration of the principle of moving the cutting tool along the circular-shaped helical wire loop.

A New Type of Machine — On a straight wire, locating the end side and starting from that position is quite straightforward. However, it is more challenging in a coil, where the wire has the shape of a continuous helical multitude of wire loops.

Any solution must also preserve the orderliness of the wire loops within the coil and be gentle and not scratch or damage the finished product. This led to the realization that, since the product that has to be processed has a circular shape, the machine that performs the process must have a similar shape as well and must be able to move in a circular manner. All the necessary functions and features must then be distributed along the circular-shaped machine.

This resulted in a completely new machine referred to as the ring processing turret, which is essentially a circular guide with a shape that follows the natural circular shape of the coiled wire. Distributed along the circular guide is an advanced pinch-roll assembly, a significant number of sensors, several guide segments and a cutting device. The actual rotation of the ring processing turret is performed by a gear motor mounted on the main trolley.

These distributed resources give the ring processing turret the ability to:

- Receive a ring from the coil and bring it into the pinch-roll assembly.
- Rotate clockwise (clockwise when facing the ring processing turret) toward the end of the coiled wire.
- Locate the end of the coiled wire and stop.
- Rotate counterclockwise (away from the located end) while measuring the exact position of where to make the trim cut.
- Locate the trim cut position and stop, followed by making the trim cut.
- Rotate counterclockwise (away from the located end) while measuring the exact position of where to make the sample cut.
- Locate the sample cut position and stop, followed by making the sample cut.
- Eject the trimmed rings to be discarded.
- Eject the sample wire for testing.

Because the ring processing turret performs its process relative to the exposed end of the coiled wire,

Figure 2

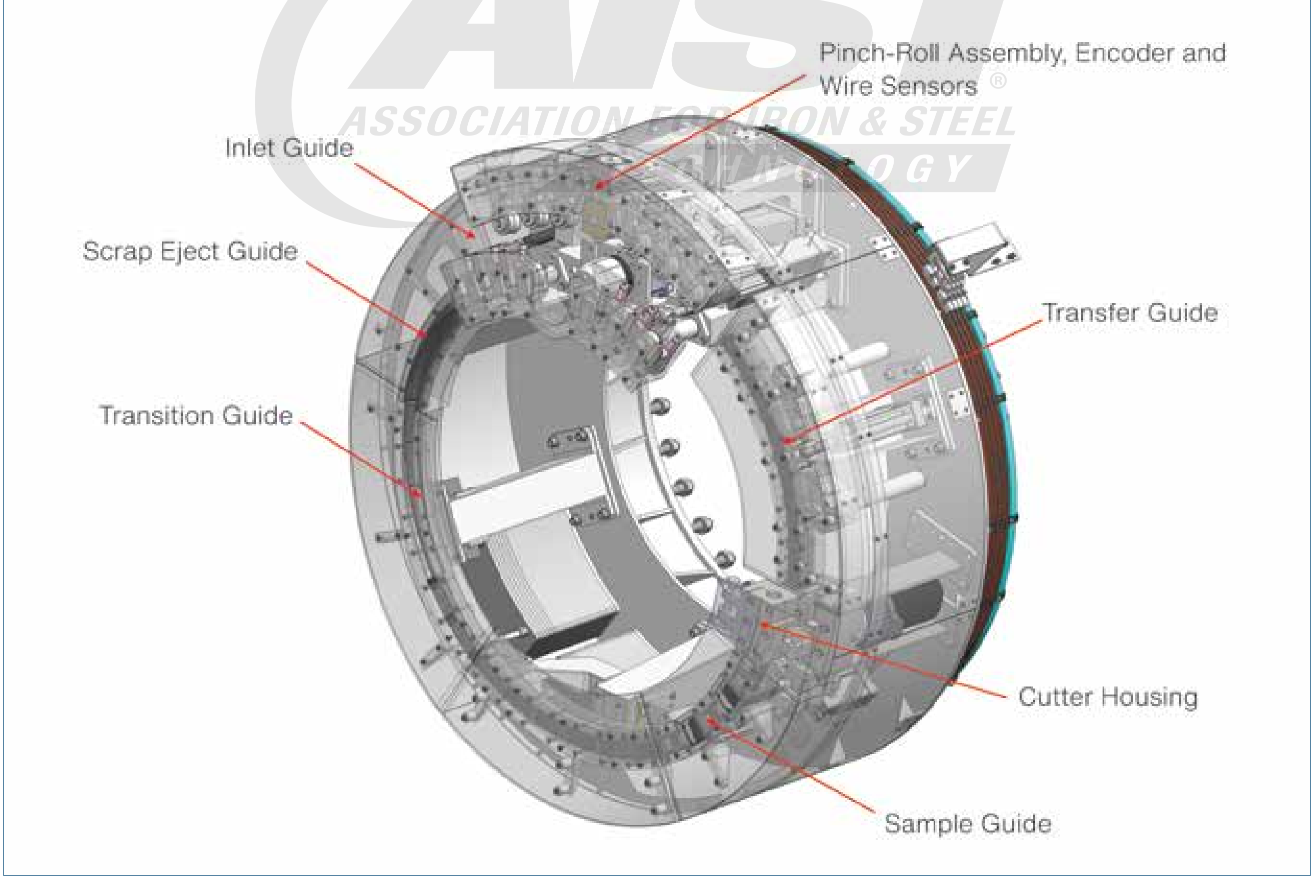


Illustration of the ring processing turret.

and not relative to the system carrying the coil, it can perform its different process steps regardless of how the coil is oriented.

Main Trolley — Because most of the existing coil-handling systems use a C-hook system, a decision was made to design the first TRIMBOT to service the trimming and sampling area in any conventional C-hook system.

The purpose of the main trolley is to move the TRIMBOT system from a rest position, located at a safe distance away from the moving C-hook, to the active forward working position just in front of the C-hook.

The main trolley consists of a fabricated welded structure equipped with standard roller assemblies intended for the longitudinal rail sections in the rigid base frame mentioned in the following. The trolley is also equipped with a gear motor driving a pinion acting on the longitudinal teethed rack on the rigid base frame. This makes it possible for the main trolley to travel along the longitudinal extension of the rigid frame between the different positions.

A separate gear motor and a large-diameter slewing bearing is mounted to the forward part of the fabricated structure. The gear motor is fitted with a pinion which is acting on the external teeth on the large slewing bearing, which in turn is bolted to the ring processing turret.

Within the main trolley, there is a separate, smaller longitudinal rail section with a separate longitudinal teethed rack. This internal rail structure is intended to support the internal ring transfer trolley as it travels within the main trolley.

A rigid base frame supports the main trolley. The rigid base frame is designed to be mounted directly onto the existing mill floor and consists of two longitudinal rail profiles and a longitudinal teethed rack.

Internal Ring Transfer Trolley — The internal ring transfer trolley consists of a lower carriage equipped with a gear motor with a geared pinion. The lower carriage is equipped with standard roller assemblies intended for the longitudinal rail sections within the main trolley mentioned earlier.

The lower carriage is also fitted with vertical rails of a similar type as the longitudinal rail sections, intended for supporting the vertical elevator carriage.

The vertical elevator carriage is equipped with standard rollers intended for the vertical rail sections in the lower carriage. The movement up and down along the vertical rails is made possible by an electrical actuator mounted to the lower carriage and acting on the vertical elevator carriage.

The vertical carriage is also equipped with two parallel arms extending out from the vertical carriage along the longitudinal axis of the longitudinal rail

Figure 3

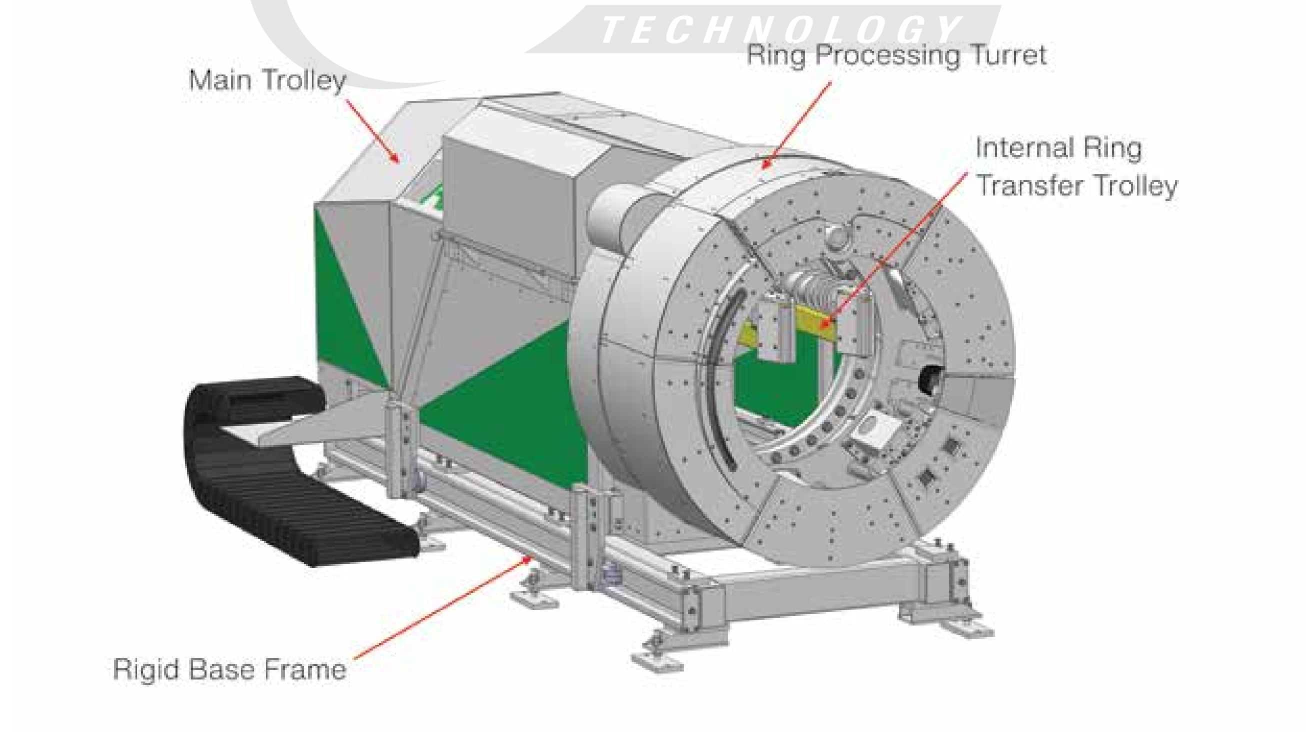


Illustration of the main trolley with the ring processing turret.

Figure 4

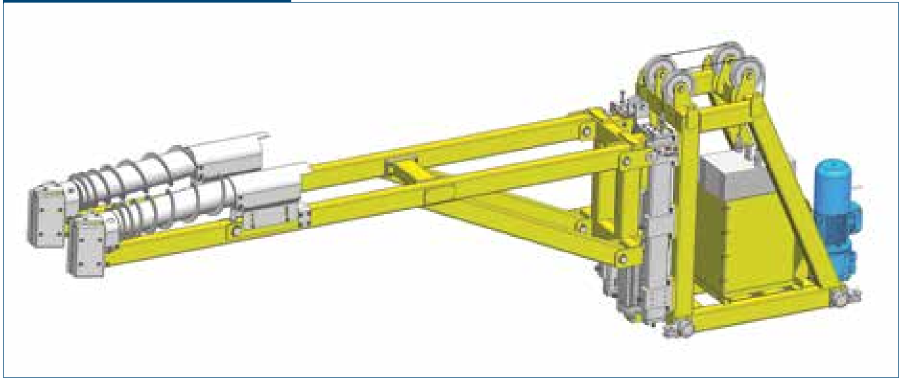


Illustration of the internal ring transfer trolley.

sections, toward the circular opening in the center of the ring processing turret. At the end of these parallel arms, there are two angled screws with opposite threads. The thread pitch on these screws gradually increases to provide a progressively increasing separation between the individual rings as they are transported from the C-hook to the ring landing, mounted to each of the two parallel arms. Each of the angled screws is powered by a separate servomotor.

Robotic System — In order to find a ring and transfer it into the ring processing turret, as well as to assist in returning any extended rings back onto the C-hook, and to handle the movement of the scrap rings and the sample wire, a robotic arm equipped with a vision system and a wire gripping tool is designed and used to support the system.

The vision system, mounted on the wrist of the robotic arm, allows precise distinction of each ring as it reaches the landing in front of the ring processing turret. The vision system captures a 3D image which is analyzed by dedicated software and enables the gripper to perform an accurate picking of the first ring followed by an accurate placing of the first ring into the extended lower receiving guide within the ring processing turret. The designed gripper will be able to grab a single

Figure 5

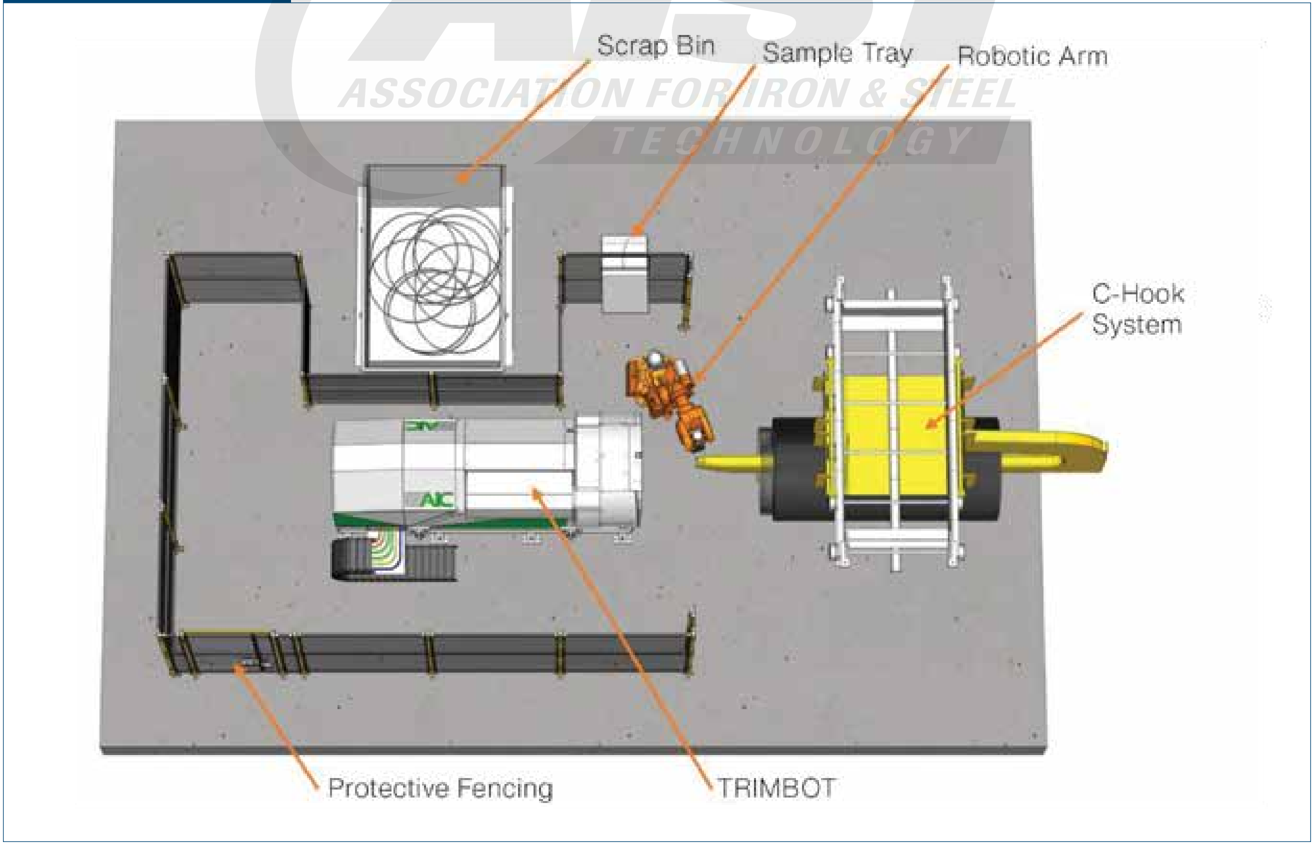


Illustration of the TRIMBOT configured at a normal C-hook coil-handling system.

ring, a single sample wire, as well as the group of rings that need to be scrapped once the trimming cut has been performed.

In order to control the movements of the robotic system, it is commanded by a dedicated control unit that can be configured as a stand-alone unit or integrated into an electrical cabinet together with the rest of the control units required for the complete automation, including the ring processing turret and all the auxiliary functions.

Electrical Control System — A dedicated programmable logic controller (PLC) is used to handle all the movements of the machine, including:

- All communications with the surrounding equipment, interlocks and trimming/sampling instructions.
- Horizontal movement of the main trolley to allow translation of the whole structure.
- Rotation of the ring processing turret and control of motors/actuators within.
- Horizontal and vertical movement of the internal ring transfer trolley.
- Rotation of the separating screws.
- Control signals to send to the shear in order perform the wire cutting.
- Position control of the rotating unit to allow a maintenance-friendly configuration.
- Interface between the 3D optical scan sensor and the image analysis software.
- Control signals necessary for the handling of the end effector/gripper tool.
- Handling of all the distributed sensor data.
- Data exchange with the existing automation.
- Handling of the safety accesses to the area.

For the robotic system, a dedicated control unit fully integrated with the automation handles all the movement of the robotic arm and allows the programming of its sequence in terms of target positions to be reached as well as conditional cycles to make sure that the ring processing turret is ready and able to receive the robot's help.

The Sequence — The basic sequence, as listed in the following, will likely change as the product and the process evolve over time. However, in this initial configuration, the TRIMBOT is working on a conventional C-hook system and requires similar interlocks as is used between a typical coil compactor and a C-hook system.

Pre-conditions before the automatic process can commence are:

- C-hook is in position and locked.
- TRIMBOT receives instruction of how many millimeters to trim and if a sample is required.

Sequential steps to place the initial wire inside the machine:

- Main trolley moves forward to the C-hook and begins to separate loops from the coil.
- Robot arm, supported by vision system, locates and picks a wire loop.
- A wire loop is placed into the ring processing turret by the robot arm.

Sequential steps to locate the end of the wire:

- Ring processing turret begins to rotate toward the end of the coil while untangling individual rings.
- All movements stop when the wire sensors detect the end of the wire.

Sequential steps to measure the distance of where to trim:

- Transfer guide within the ring processing turret is extended.
- Ring processing turret begins to rotate away from the end of the coil.
- When the rotary encoder detects that the cut point is in the center of the shear, the ring processing turret stops.
- The shear within the ring processing turret extends its movable blade and the wire is sheared.

Sequential steps to measure the distance of where to cut a sample:

- Ring processing turret begins to rotate away from the end of the coil.
- When the rotary encoder detects that the cut point is in the center of the shear, the ring processing turret stops.
- The shear extends its movable blade and the wire is sheared.

Sequential steps to return trimmed coil to C-hook:

- Ring processing turret rotates toward the end of the coil until the new end has exited.
- C-hook is released and a new C-hook with coil moves into position.

Sequential steps to discard trimmed rings:

- Main trolley retracts to unloading position.

- Robotic arm with vision system identifies the trimmed rings and moves into position to grip the trimmed rings.
- Gripper closes on the trimmer rings and the robotic arm transfers them to the scrap bin.

Sequential steps to discard sample wire:

- Main trolley moves to the sample receiving position.
- The sample guide extends and exposes the sample wire.
- Robotic arm with vision system identifies the sample wire and moves into position to grip the sample wire.
- Gripper closes on the sample wire and the robotic arm transfers it to the sample tray.

After completing the trimming and/or sampling sequence, the TRIMBOT returns to its start position and awaits a new start sequence. The estimated time required to perform any single trimming sequence is 45–60 seconds, depending on the length of wire that must be trimmed and removed. A single sampling sequence will add approximately 20 seconds to the above trimming sequence. The trimming capacity is limited to the payload of the robotic arm. The current configuration is limited to 100 kg in a single lift.

Conclusion

Given that coil-handling systems in general are designed to integrate humans into the process, it is unlikely that it will evolve in any significant way. As a result, when rolling mill technology continues to evolve and produce at a faster pace, the only response from the average coil handling supplier is to make the system bigger and add more equipment.

With the introduction of the TRIMBOT, this can actually change. By no longer being tethered to the requirement of designing systems where humans are involved as an integral part of the process, future coil-handling technology is free to evolve based on what is advantageous to the requirements of the process and the finished product itself.

The completely electric TRIMBOT is designed to fit and operate in almost any existing coil-handling system with minimum disturbance to the existing equipment in the case of already-producing mills, and also to be integrated in brand-new lines. It is primarily designed to replace any existing ring counting process, but its value to the rolling mill extends beyond only replacing the human operators in the finishing end areas by offering a level of trimming accuracy that isn't possible on a ring counting trimming method. The novel trimming process makes it possible to reach a trimming accuracy of ±5 mm under certain conditions. Considering this level of accuracy, it becomes relevant to adjust the actual trimming position based on the dynamic variations in the rolling process for each individual coil. Therefore, the dynamic trimming feature is introduced, intended to further reduce waste and yield losses, improving safety for humans at the finishing end areas. ✦

AISTech
This paper was presented at AISTech 2022 — The Iron & Steel Technology Conference and Exposition, Pittsburgh, Pa., USA, and published in the AISTech 2022 Conference Proceedings.

Figure 6

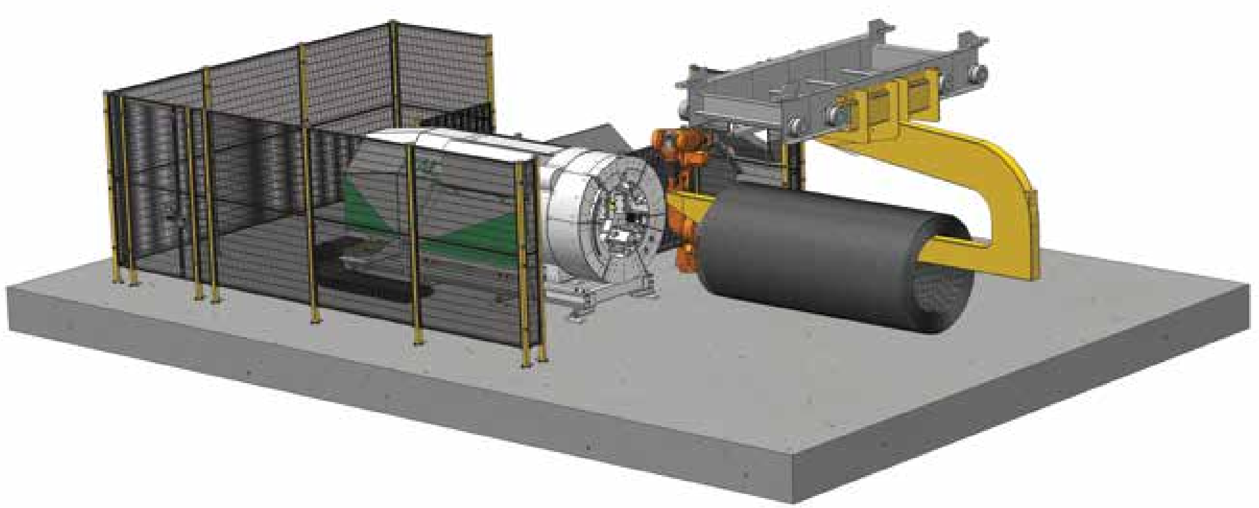


Illustration of the entire TRIMBOT station.