

Vision-Guided Robotics Provide a Flexible, Automated Billet Tagging Solution

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INTRODUCTION

Steel mills have recognized the need for tagging material as it comes out of the caster for many years. Both integrated mills and mini-mills, whether producing slabs, billets, blooms or blanks, have used metal tags as a way in which to accurately identify and track product for both internal purposes and for external customer demands. Information, such as heat numbers, stand numbers and cut numbers, give mills the ability to track and trace back in order to ensure quality standards.

Despite the process of attaching a metal tag with identification information being commonplace for many years, steel manufacturers have struggled with implementing solutions that can reliably automate the actual attachment process. Many organizations have relied on nail guns or manual welding processes to affix the metal tags. Manual attachment methods can expose workers to dangerous levels of heat and repetitive motion processes that could result in long-term injuries.

Concept Systems Inc (Concept) started discussing the development of an automated billet tagging system with Nucor Steel's Berkeley Division (Nucor) in early 2012. As with many projects they perform, Concept took a consultative approach to proposing the system, using valuable input from Nucor on processes and preferences in order to develop a system catered specifically to their facility's needs. An order for an automated tagging system, now known as BilletID, was placed in early 2013 with the installation taking place in the Fall of 2013.

This paper discusses this specific installation of an automated tagging system that utilizes a combination of vision guided robotics and capacitive discharge stud welding to provide a flexible system with a solid return on investment.

BACKGROUND INFORMATION

Tagging steel product as it comes off the caster has been a practice employed by various steel mills for many years. The primary reason behind this practice is to implement traceability for material that has been cast, but has yet to be processed. For mills that run a variety of grades, understanding the heat number that the steel came from is essential in determining what the end product will be rolled or processed into. If the product is not going directly into the secondary forming process, rather is being stored temporarily in an inventory yard, having a way to identify the product type is absolutely essential.

For mills that are not currently tagging product, there can be major justification in beginning to track product as it exits the caster. In the past, many mills may not have had a diverse product mix and could get away with not tagging or tagging the first and last billets of a specific heat. As competition increases, it is becoming more important to find new markets or new ways to offer value to customers. Having this type of traceability process can be a huge selling point for new customers or selling steel into new markets. This traceability program is seen as a necessary component for current merchant bar mills looking to develop into a SBQ mill.

Over the years, a number of other methods for trying to mark and trace steel have been tested. Some of those processes include indenting or painting heat numbers to the ends of the product. The major downside of this type of marking is that it requires extremely high end machine vision systems to perform optical character recognition (OCR). These vision systems are not only expensive, but rely heavily upon consistent lighting as well as consistent mechanical application of the marks, which is difficult to ensure in a steel mill environment. Furthermore, the sole use of characters limits the amount of information that can be tracked as the product goes through the process. On the other hand, the use of a metal tag, containing characters and barcodes, allows mills to utilize lower cost common off the shelf 2D code readers for tracking the product as it moves throughout the process.

Automation of a manual tagging process makes business sense for a variety of reasons. As many mills look to improve the safety of their processes, the automation of the tagging process is an area that offers immediate improvements. The area where hot steel tagging typically takes place is a dangerous location with the combination of close range exposure to high temperature steel and risks associated with overhead crane traffic. Furthermore, the act of tagging, which has traditionally been done using nail guns, is a very physically intensive, repetitive process typically using costly and potentially dangerous consumables.

The elimination of these safety risks alone can often justify the cost to automate the tag attachment process. Reliability of the tagging process is yet another area in which an automated tagging process can provide a return on investment. When performing manual tagging, there are a few potential instances that can create reliability issues. If you consider a typical tagging operation, an operator typically prints off several tags in a remote room. After printing off a series of tags, the operator will carry those to the tagging location. At this point, there is a high chance of human error that the tags could be mixed and not affixed in the proper order. If a tag is dropped or left in a pocket, the tag order will be off by one for a considerable period of time, creating the potential for miss-marked heat numbers. The combination of the safety and reliability risks relating to human tagging has led many mills to look for options to automate this process. Furthermore, typical tag affixing nail guns include a small plastic component on the nail that inevitably melts then burns creating a black smear or blemish on the tag as well as a small amount of toxic fumes as it combusts, potentially creating challenges to reading the tag.

Concept Systems was approached by Nucor Steel primarily due to our experience integrating unique vision-guided robotic systems into challenging environments. Though work conducted in a variety of industries, Concept brings unique perspectives on technologies that are proven, but under-utilized by certain industries. Although the technology is not usually on bleeding edge, the combination of technologies into complete solutions that are deployed by Concept Systems are often recognized as innovative game changers to companies and industries. Nucor Steel recognized that the technologies involved in a successful deployment of an automated tagging system would be right in the wheelhouse for Concept Systems.

DESCRIPTION OF SYSTEM

The system that Concept Systems' has developed is designed to operate in a mostly unattended fashion. This section will provide a very broad overview of what the system does and how it operates. In the installed application at Nucor Steel – Berkeley Division, steel billets, blooms or blanks will move across the cooling bed from the 4 strand caster. Once the group of bars have indexed into position, the robotic system will receive a discrete signal from the plant PLC to start the tagging process. Upon receipt of the signal, a heat shield barrier is lowered and a six-axis robot moves to perform a 3D laser scan for the bar positions. The system uses a 3D laser scanner in order to create a point cloud image to fully understand the position of the steel billets on the cooling bed for the purposes of welding position, and to determine if the bar already has a tag. Concurrently, the system's SQL database is receiving production information such as bar number, heat number, strand number and cut length from the mill's Level 2 system. Once received by the SQL database, it is located a short time later and put into the tag printing queue. Typically the SQL database is loaded prior to the group of bars being pushed into position to allow the burning laser to start burning the tags.

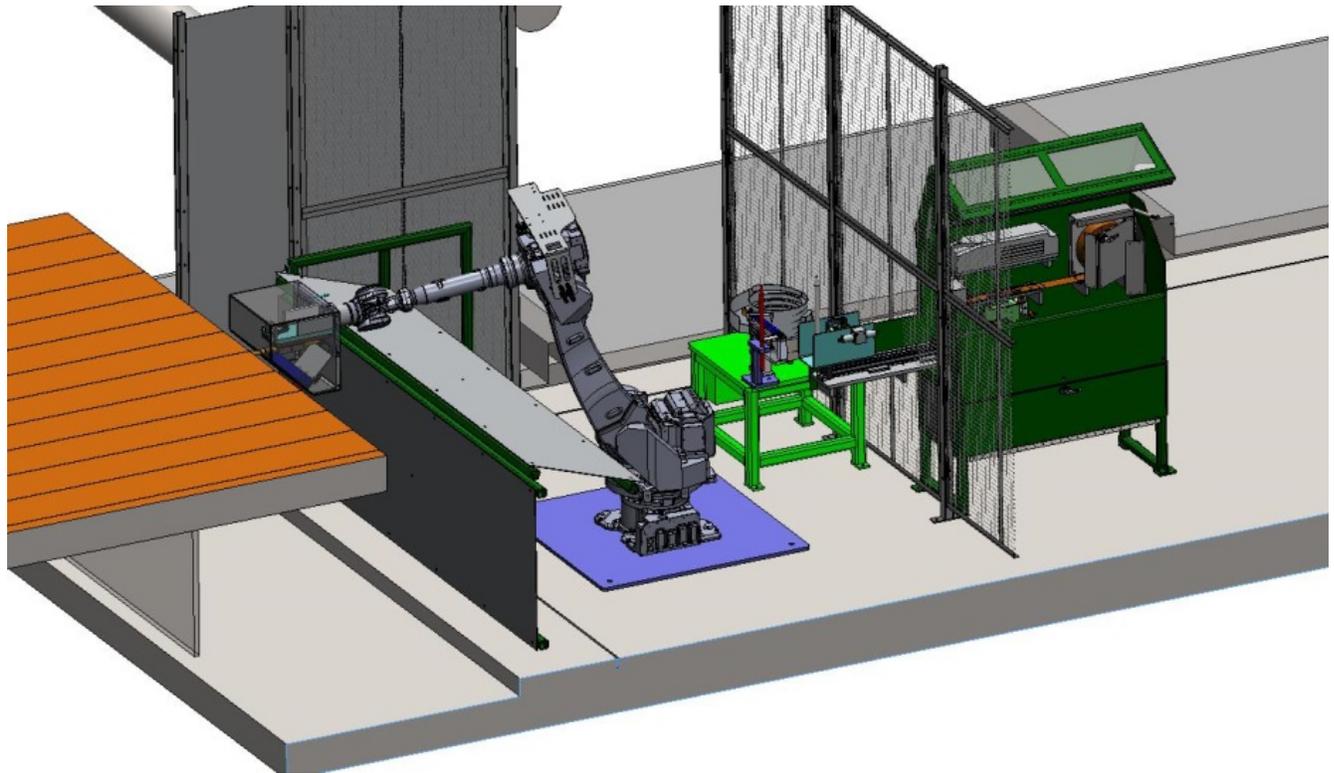


Figure 1 - System Overview

Once the 3D scan is performed, the robot moves to a bowl feeder (shown as a light green stand in Figure 1) where it picks up a stud. Once the system has brought the stud to the verification station and the stud is verified, the robot then moves to the tag feeder machine (shown as a dark green machine in Figure 1) where it picks up the tag printed with production information. The robot then takes the tag to the verification station to ensure it has properly been loaded. With the robot end-effector loaded with the stud and tag, it moves back to the steel billet where a weld tip controlled by a pneumatic cylinder extends create contact with the stud and billet. The system uses a capacitive discharge welding technique to affix the metal tag to the billet end.



Figure 2 - Billet End with Tag

After the welding is complete, the robot uses a Cognex Dataman 2D code reader to ensure that the tag adhesion was successful and that the tag is readable. After a successful read, the SQL database is updated with the verification time and date for the tag, and the

robot continues to repeat this cycle until all the billets within range have been tagged. Upon completion of welding all the tags, the robot lowers into its home position, the heat wall drives up to protect it from radiant heat, and the PLC is notified that the robot has moved outside of the tagging zone.

With less description, here is a typical sequence of operations:

1. The operator will put the system into Auto mode
2. The system will determine if the system is ready to affix a tag by performing the following steps:
 - a. Perform a scanner aiming test
 - b. Determine if the tag printer is functional and enabled
 - c. Determine if it already has a stud or tag in the end effector
 - d. If no stud, then determine if a stud is ready to be picked up
 - e. Move the robot to pick the stud up
 - f. Check to see that the stud was properly picked up
 - g. Determine if a tag is ready to be picked up
 - h. Move the robot to pick the tag up
 - i. Check to see that the tag was properly picked up
 - j. It will request PLC permission to enter the weld area

Asynchronous to the overall sequence of operation, the tag printing system will perform the following tasks when in Auto Mode:

- I. Wait for tag information to appear in our database table
- II. Move the tags from the database table into our tag queue, then clear out the table.
- III. If we can print a tag, command the tag printer system to create a tag with the correct information on it based upon the queue, then advance the queue one space
- IV. Move the printed tag information into the Tag History database table. It will include information as to the origin of the tag information, either Level 2, or manual.

Returning to the system sequence of operation

3. Wait for the PLC to indicate that it is OK to enter the weld area
4. Scan the steel to find the first piece that does not have a tag
 - a. If no billets are found without a tag, then return to home, release the request to the PLC for access, and wait until the PLC indicates that the pusher system has sequenced additional billets into the weld area
 - b. If a billet is found, then continue to step 9
5. Verify the last tag affixed. This is done to ensure that what looked like a stud was actually a stud on a tag rather than random slag. If the verification succeeds, then the next weld location is used. If it fails, the current weld location is used.
6. Move the robot weld tip near the appropriate billet
7. Extend the weld tip using the pneumatic cylinder with approximately 50lbs of force
8. Actuate the welder to weld
9. Retract the welder
10. Move to scan the tag with the barcode scanner
 - a. Allow up to 4 seconds for the barcode scanner to read the code (it may be blowing in the breeze and temporarily unreadable).
 - b. If after 4 seconds, then assume that the barcode is unreadable
 - c. If the tag was read, immediately record the pass/fail in the Tag History database table for the given tag
 - d. If the tag read failed, create a local alarm and also create a global alarm on the pulpit PLC control system that a weld failure occurred. Switch to manual mode and release permissions.
11. If there are more tags to attach, go back to step 6. Note that the tag printer system will be commanded asynchronously to the robot system with the intended goal of trying to having a tag printed and ready for the robot prior to its need. Also note that the system will keep the request to control enabled until either all of the tags in the queue are affixed or no more billets are found to attach tags to.
12. If all tagging is complete move back to home and raise the heat shield
13. Signal to the PLC that tagging is done, then wait for the push indication from the PLC.
14. Return to step 3

SYSTEM COMPONENTS

The system itself is made up of a variety of off-the-shelf components that will be outlined in depth throughout the upcoming section. Concept Systems insists on using class leading off-the-shelf hardware in every project, making it easier for Nucor or any end user to source parts from local distribution channels that they already have relationships with.

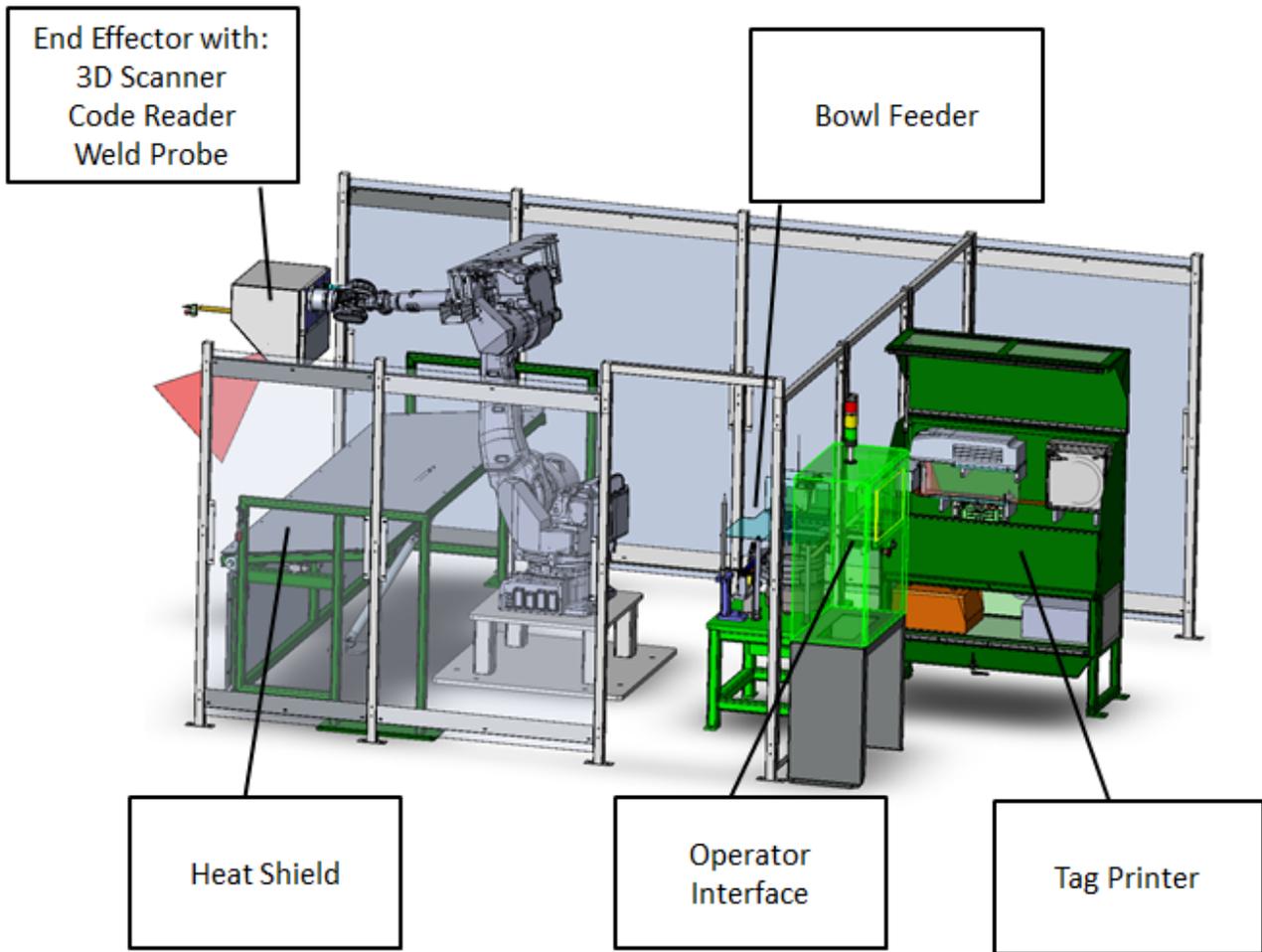


Figure 3 - System Overview with Select Main Components

3D Laser Scanning for Vision Guidance

One of the most critical components in the overall system resides within the end effector of the robot. The 3D laser scanner is the component that allows our system to be so flexible and is really what gives the automated system its best-in-class reliability. To perform the critical scanning work, we utilized the capabilities of the Hermery SL1880 scanner. The system used this SL1880 scanner, along with PC-based processing in order to provide the system with the following:

- Exact location of the position of the billet in 3D space
 - Accurate tagging position regardless of position (x, y or z)
- Sense rough ends in order to intelligently adjust the final tag position (weld area angle), ensuring weld success
- Automatically changes program based on product identification (billet, bloom, blank)
- Provides real-time tag placement verification
- Used as a collision avoidance sensor to prevent robot crashes with unexpected intrusions

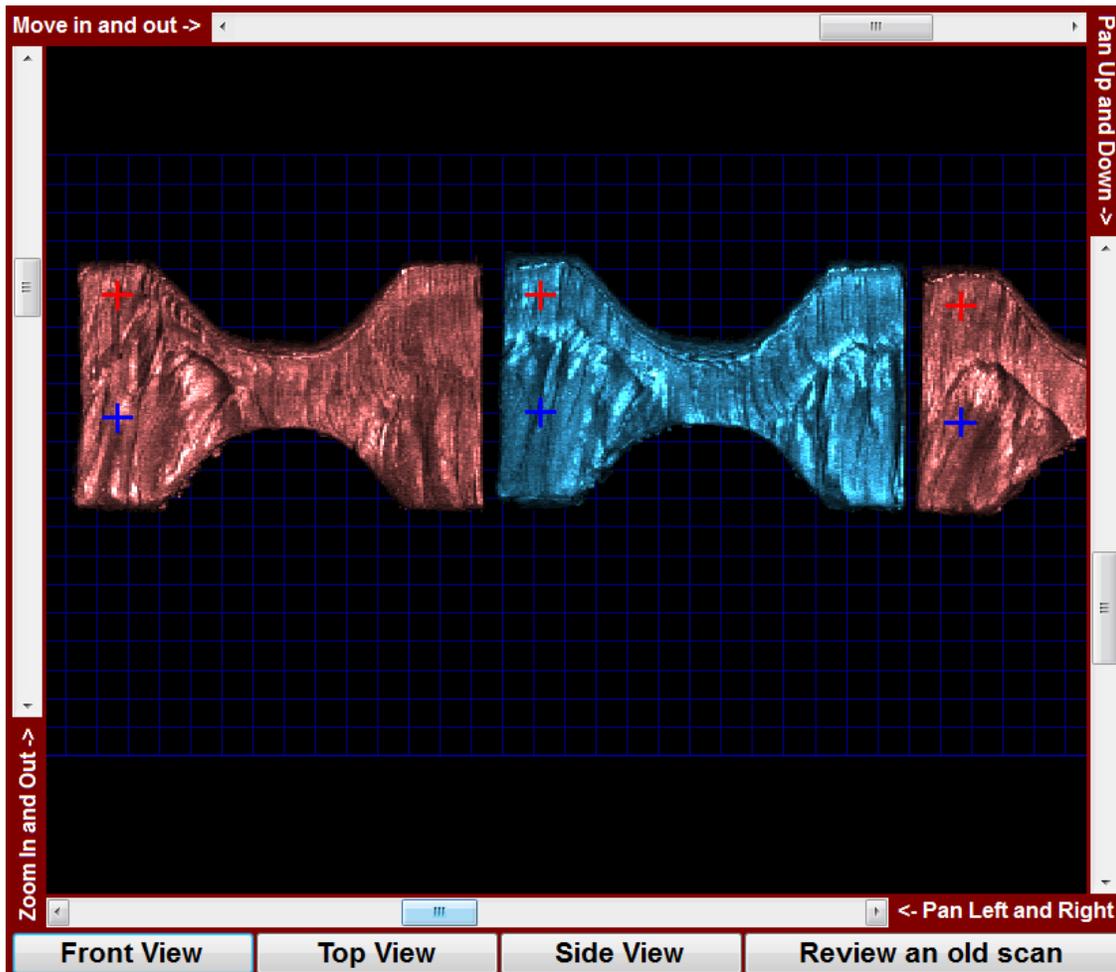


Figure 4 – Actual Point Cloud Data showing Billet Surface. Blue grids are one inch square.

As described above, the performance of this scan is the most critical aspect of implementing an automatic tagging solution and allows that solution to be flexible enough to meet the needs and demands of nearly any mill's current manufacturing process. Without major mechanical retrofits to the cooling bed, a blind robot or tagging system would be incapable of accommodating the variances in position and product. Furthermore, the reliability of the weld itself increases greatly by have such precise positional information. Nucor Steel recognized the importance of this 3D scan early on in their decision making process and the flexibility and reliability gained through its usage was a primary driver for selecting this solution over other proposed solutions

The way the scanner works is to project a laser line, and then views the laser line at an angle using a camera, often times called triangulation. This camera sees the laser line at the top of the imager when the object being scanned is far away and the laser line appears at the bottom of the imager when the object is close to the scanner. The scanner can generate 680 calibrated points per scan, and the system will receive 200 scans per second, generating a possible 136,000 X and Y calibrated points per second. In reality, the scanner will not be totally blocked by the part, so a smaller subset of this data stream will be utilized, in the order of 30,000 points per second.

The scanner has a minimum standoff is 18" from the front of the scanner, and at this distance the scan window is 14" wide. The maximum scan window depth is 60 inches, but this application did not utilize the entire scan window, but utilized the near field of the scan window to increase accuracy and also to work within the reach of the robot. In the near field, the scanner is accurate to approximately .020" in the Z dimension (the part to scanner distance directly in-front of the scanner)

When scanning the steel, the robot goes through a pre-defined path programmed in the robot, and this path will be pre-modeled in the scanner software to render an accurate 3D model. The result is what is referred to as a point cloud, although our scan data is augmented by an intensity value for each point, creating a realistic looking 3D image of the end of the bar (show in Figure 5).

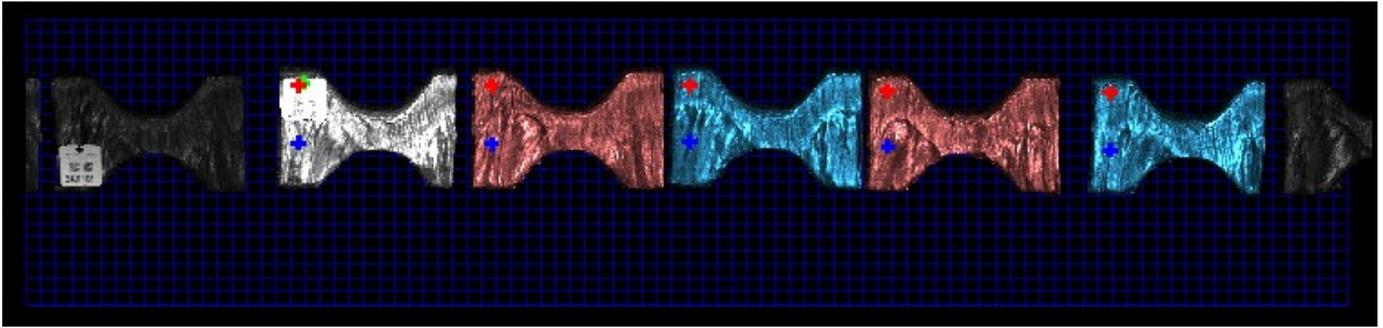


Figure 5 – Actual Point Cloud Data Showing Blanks on Cooling Bed

Evaluation – 3D Scanning versus Point Laser

For this application, Concept evaluated using a point laser versus a line-scan laser as the primary feedback device, and has developed a series of reasons that led us to the line-scan laser 3D approach. The initial cost of a 3D laser scanner is substantially more than a basic laser displacement sensor. However, it was determined that the Total Cost of Ownership (TCO) of having that 3D scanner would be substantially less over time. As part of our initial evaluation that we performed, it was determined that the primary impacts on TCO were downtime. The primary culprits of downtime were robot collisions with the parts, addition robot maintenance, and inconsistent tag application – which means the system is not capable of tagging the center of every piece of product, regardless of any variances in location/orientation, within the allotted cycle time.

The Hermery SL-1880 scanner approximates 680 point lasers with each laser operating at 200Hz. This allows the system to provide up to 680 calibrated X-Y values 200 times per second, translating into a maximum of 136,000 data points per second. More data equals more redundant data, and more redundant data equals more, quality data to allow more informed control decisions to be made. This fact alone is the basis of the many TCO benefits the line-scan laser offers.

Point lasers usually update 1000 times per second (1000hz) and depending on the model you use, you can get similar accuracies to a line-scan laser for a given measurement range. Under laboratory conditions, you can receive a maximum of 1000 points per second, which is a striking difference than the quantity delivered by a line scan system. To arrive at a 3D point, you must gather the robot position along with the end effector rotations to achieve a true 3D point. Furthermore, the positioning of the point laser is very critical since the laser needs to be orthogonal to the part to obtain useful information, but the part orientation is what we are trying to determine using the point laser, creating a conundrum that requires making guesses and then using the laser to refine the guesses into a model. Using a point laser, more time is required over the part as the system first establishes, and then gathers the two planes required to create a basic 3D model.

It is clear that the line-scan laser will result in better cycle times, which leads directly to more system flexibility. For example, in the case that additional parts are indexed prior to tagging completion, with the line-scan laser, the parts can be quickly rescanned and tagging resumed, likely without impact to the overall cycle time of that part cluster.

Not only does the point laser method eat into precious cycle time, the additional time near the steel increases the sympathetic heating of both the robot and the sensor, which will likely reduce the life of the sensor, while exposing the robot to unnecessary wear and tear. The additional wear of the robot created by increased movements and cycle time will translate quickly into downtime relating to the maintenance of the robot.

Since the point laser will need to be orthogonal to the part to provide a precise measurement, it is important to utilize the necessary cycle time to properly position the point laser. If this is not done, the ability of the system to accurately determine part dimensions and differentiate between neighboring parts is greatly diminished. Without proper dimension, location, and orientation information, the consistency of tag placement is greatly diminished. With a line-scan laser the planes of the part surfaces can be determined intrinsically, on the fly from the data stream, so these issues do not exist. You receive the dimension, location, and orientation information you need, leading to accurately tagged parts, at greatly reduced cycle times.

While it is feasible that, given enough time, the required modeling and positional accuracy can be done with a point laser, it will require a lot of time over the part and/or a strict set of rules on how the parts are presented to the system. Variances from these rules will result in collisions between the robot and the parts and product, as mentioned previously, that are unable to be scanned and/or unable to be differentiated from neighboring parts, resulting in misapplied or missing labels.

In this application, it can be plausibly assumed that the parts are oriented correctly and have the robot execute a pre-defined path which will gather the critical data needed to apply the labels using a point laser. The risk is that there is no easy way to pre-verify the path (i.e. verify the assumptions) to ensure there is nothing in the way prior to making the movements. With a line-scan laser, the robot can point the sensor toward the path and in only a fraction of a second know if the path is free of obstruction prior to moving the robot through the points. As described above, this prevents collisions, reducing downtime and damage that could occur to the end-effector and/or robot.

Quality sensor information enables any control system to make better decisions. With the fewer assumptions, more data and additional verifications provided by a line-scan laser, the system can be made measurably more reliable. The reliability will be recognized through a reduction in downtime, better cycle time and a more consistent tagging application. It should be pointed out that in this application, an unanticipated collision between the robot with its sensors and welding equipment and the part is not an insignificant event that can be recovered from easily. For these reasons and more, Concept selected the line-scan laser approach since it represents the most cost effective solution from a TCO perspective.

Software Application

The heartbeat of the system is a standard off-the-shelf Dell laptop computer equipped with a 256GB Solid State disk, Quad Core I7 processor, 8G memory, nVidia graphics and running Windows 7 64bit professional. The reason a laptop is selected is to conserve space, increase ruggedness, and laptops are generally better equipped to operate in a challenging environment than desktop computers, including better thermal management features. The laptop is housed in an air-conditioned, dust-tight enclosure.

The software was developed in Visual Studio 2012 (Visual Basic.Net). All the graphics work on the operator interface is performed in OpenGL graphics and use the standard open source OpenTK libraries. Communications to the Nachi robot was performed using standard UDP sockets written to a custom Nachi background task. Concept Systems has a standard policy to always provide all source code to the customer without any passwords or other copy protection instruments. Similar to utilizing off-the-shelf hardware, this enables the customer to take full ownership of the system and not be reliant on the integrator or machine builder. This standard 'open source code' policy employed by Concept Systems was another major factor that led Nucor to selecting Concept Systems for the development of this system.

Robot & End Effector

The robot that was used in this application was a Nachi MC50 robot with their FD11 controller. This is a multi-use robot that is designed for welding applications with all of the motors either in the base or in the elbow for additional thermal protection. Furthermore, the system was outfitted with suit made of Aluminized Preox with a Silver Ansotex Liner. This suit is designed for high heat areas and protects the robot from higher ambient temperatures, in addition to the fine metal dust that is typical in a steel mill.



Figure 6 - Image of Uncovered End Effector

The end effector houses the Hermery 3D laser scanner, a Cognex 2D code reader, the weld probe and a Vortex Cooler. An image of the end effector without its protective aluminum cover can be seen in Figure 6. The aluminum cover and interior Vortex cooler is in place to keep the temperatures of the electronics lower than the ambient and to provide a nominal positive pressure. Hermery Opto has equipped this model of the SL-1880 with a feature that provides head temperature data embedded in each scan. This temperature reading comes from an internal thermocouple in the scanning head, allowing the system to continually monitor the temperature of the electronics within the end effector.

Capacitive Discharge Weld Gun

The basis for the tagging concept is based on a Capacitive Discharge method for welding a collar stud onto the end of the billet. This process has documented success within the steel industry and has been utilized with billets through a manual operation for several years.

The Stud has been specially designed to be attached to the rough edges of the billets and has a special coating that allows the stud to be used with the higher current needed to attach the stud successfully to the billet end.

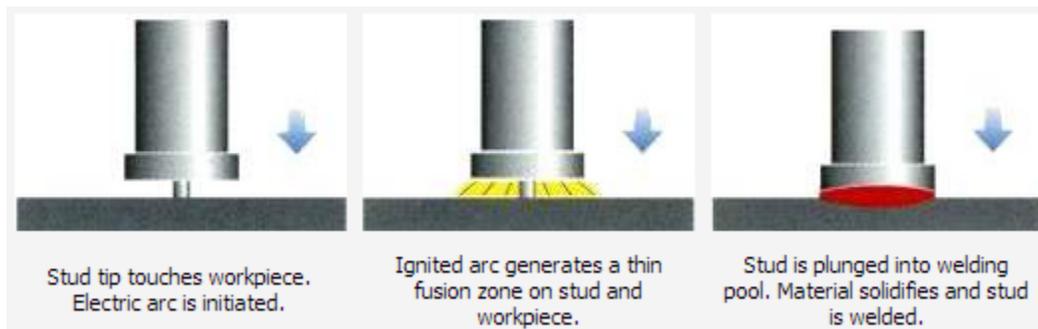


Figure 7 - Capacitive Discharge Welding Method

“The CD process operates on the principle of capacitor stored energy which is instantaneously discharged by the equipment system through a special weld "timing" tip. The tip not only controls the time of the energy transfer it also controls the path, acting as a pilot arc to start the energy transfer between the stud and the base material. This characteristic melts the metal at each surface (stud base and working metal) and then the spring pressure from the gun plunges the stud into the work area. Since the entire weld cycle is completed in milliseconds, welds can be made to thin sheet material without pronounced distortion, burn-through, or discoloration. CD Stud Welding also permits welding of dissimilar metals as long as they are compatible.” (Southern Stud Weld, 2013)

Comparison of Welding Methods

Concept evaluated different tagging methods when initially brainstorming with Nucor and has provided the following comparison in tagging concepts (Capacitive Discharge Stud Welding and MIG Welding) in an effort to illustrate our decision making process towards one technology, while also understanding the associated consumable costs. The capacitive discharge method provides the greatest operational equipment efficiencies (OEE) and the hard costs associated with consumables for each method are somewhat comparable once all the considerations have been taken into account, resulting in a lower cost of ownership for the CD method.

The following chart illustrates some of the details that we weighed when evaluating the different tagging methods:

	Capacitive Discharge (CD) Stud Welding	MIG Welding
Reliability	Proven technology in steel tagging applications Allows more variability in steel position	Needs precise arc distance control for high reliability
Safety/ Environmental	None identified	Presence/storage of bottled gas Spatter likely to occur
Costs	Stud Consumables may be	Wire and gas consumables are

slightly higher cost than wire and gas consumables	less than studs on a per tag basis
Storage of Stud inventory	Arc distances need to be controlled; require more in-depth vision programming Storage of gas tanks
	Tag costs are roughly twice as much for a bare edge tag

Figure 8 - Comparison of Welding Methods

It is traditionally very difficult to estimate the feed and hourly deposition rates that will be required by the robotic welders for a reliable weld. With that said, at the request of first end user to implement this system, we made general assumptions to help estimate the consumable costs relating the deployment of each of the adhesion technologies. For the sake of our calculations, we have assumed that a mill is processing 6 billets every 2.5 minutes for a total of 144 billets per hour. Based off this tact time, we assumed that you will need to have at least 30 minutes of “arc-on” time per hour in order to perform reliable welds.

	Capacitive Discharge (CD) Stud Welding	MIG Welding
Studs	\$500 / 5000 studs	\$0
Wire	\$0	\$10 per hour*
Gas	\$0	\$3.45 per hour**
Gas Cylinder	\$0	\$0.03 per hour
Gas Storage	\$0	\$??
Damaged Tips/Cones	\$0	\$??
	\$14.40 per hour	\$13.48 per hour****

*Assumes MIG wire cost of \$2 per/lb, “arc-on” time of 30 minutes per hour for a 5lb/hr usage.
 **Assumes Argon cylinder with re-fill cost being \$75 per 330cuft cylinder (\$0.23 per cubic foot). MIG gas flow rate of 30cuft/hr with arc on time of 30 minutes for a 15cuft/hr usage.
 ***Assumes Qty. (5) 330cuft cylinders leased at \$50/year (assumes 24/7 operation in cost calculation).
 ****Does not include damaged cones and tips by inconsistent arc distances, costs associated with storage of the gas or costs associated with re-welds.

Figure 9 - Comparison of Consumables

Something that is not outlined in Figure 9 is the consumable costs of the actual tags. Spot welding through MIG welding requires a specialized tag that has bare edges. These tags undergo an additional step in the manufacturing process that results in significant per tag price increase (prices between 1.5-2 times the cost of a standard tag have been seen).

In any type of tag application method, the most important aspect of successful attachment to the steel will be the positioning of the gun or welding apparatus. Our ability to perform this reliable positioning goes back to our initial 3D scan of the product. In order to allow TIG or MIG welding to be as reliable as the CD Discharge method, there would be a significant amount of additional vision programming required. This additional vision programming would be needed in order to keep the arc distances fairly consistent throughout the rough edge of the steel.

Tag Printer

The system used a Keyence ML CO2 laser that communicates serially with the system laptop. The tag format was created in the Keyence software and the fields are updated over the RS-232 data link quickly and efficiently. All of the hardware that processes the tag is pneumatic and run in a timed, open loop manner using flow controls. This simple, yet highly predictable system is nearly bulletproof due to the high force capability and the low force requirement for each subsystem, relying on the flow controls to keep the shock forces very low. All of the various limits are mechanically adjustable and the timing for the whole arrangement is tunable from the operator interface screen.

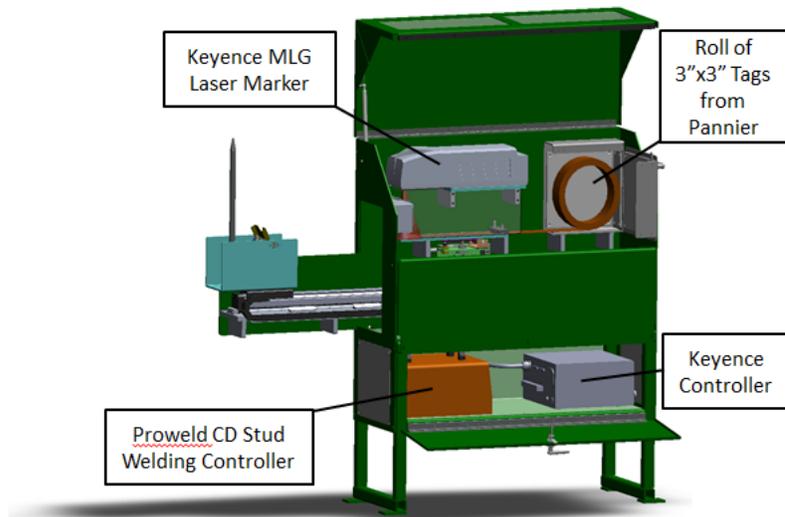


Figure 10 - CAD Model of Tag Printing Machine

Stud Feeder

Concept provided a vibratory bowl feeder developed by California Vibratory Systems that reliably feeds studs to a dead nest. The studs are detected in the dead nest as a permissive to the robot, and in the very unlikely event that the stud is mis-fed upside down; the system uses a high precision photoeye to detect this situation well in advance of it becoming a problem. The tunable bowl feeder allows the operator to adjust the replenishment rate as well as the dead nest backpressure individually. Since the whole bowl feeder exists inside the robot cage, we equipped it with a flap covered funnel to allow the operator to fill the bowl from outside the cage. A large steel top keeps the dust from falling into the bowl and our stud and tag detection photoeye is mounted above in a convenient place.

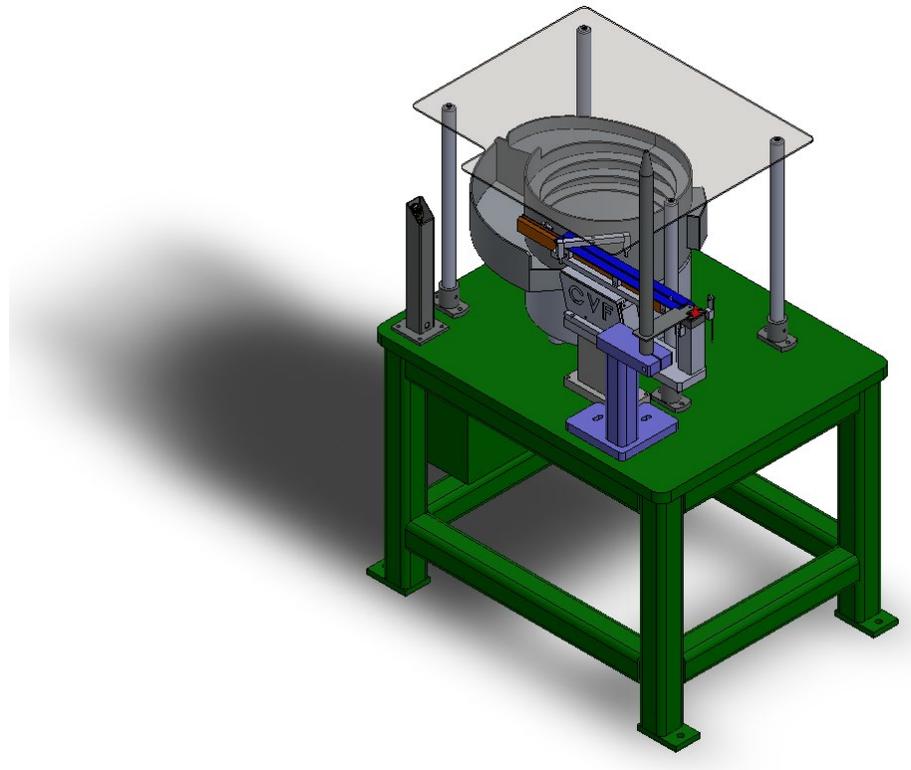


Figure 11 - CAD Model of Stud Feeder

Tags

When determining what tag to use for this system, Concept Systems' looked to the end user for initial suggestions. In an effort to make the system as simple as possible to transition from the manual process, Concept selected a tag that the end user had recently standardized on, which was a 3" by 3" square tag produced by Pannier Corporation.

As mentioned above in the cost comparison between welding methods, a secondary benefit of the capacitive discharge welding method comes in to play when looking at the consumable costs relating to the tags. Systems that depend on MIG welding require special tags, usually consisting of a bare edge or uncoated edge, allowing for a successfully spot weld to be performed. These tags go through an extra step in the manufacturing process and can often cost nearly twice as much on a per tag basis.

The tags are coated with a white color to allow the laser marked information to be easily read by downstream code readers or humans. The tags are rated to survive temperatures up to 1700°F, so they can withstand the billet temperatures as the steel comes out of the caster, but are typically melted away during the reheating process. Pannier offers a variety of tag sizes, so they can be customized based on the required amount of information that would be printed on the tag.

A typical mill would want to have at least the following information on the tag:

- Barcode containing the following information:
 - Heat number
 - Strand number
 - Cut number
- Text or 'human readable' containing the following information:
 - Heat number
 - Strand number
 - Cut number

This information is primarily used if the billets are being used internally. If the mill ships unprocessed product to external customers (either other mills within their Company or specific rolling mills), the system is also capable of printing logos, destination purchasers' name and other valuable shipping information.

Operator Interface

We installed a 22" Hope Industrial Touchscreen mounted on the outside of the panel for use with the internal laptop. This enables plant personnel to monitor the robot, scanner information and provide start/stop and error diagnostics capabilities.

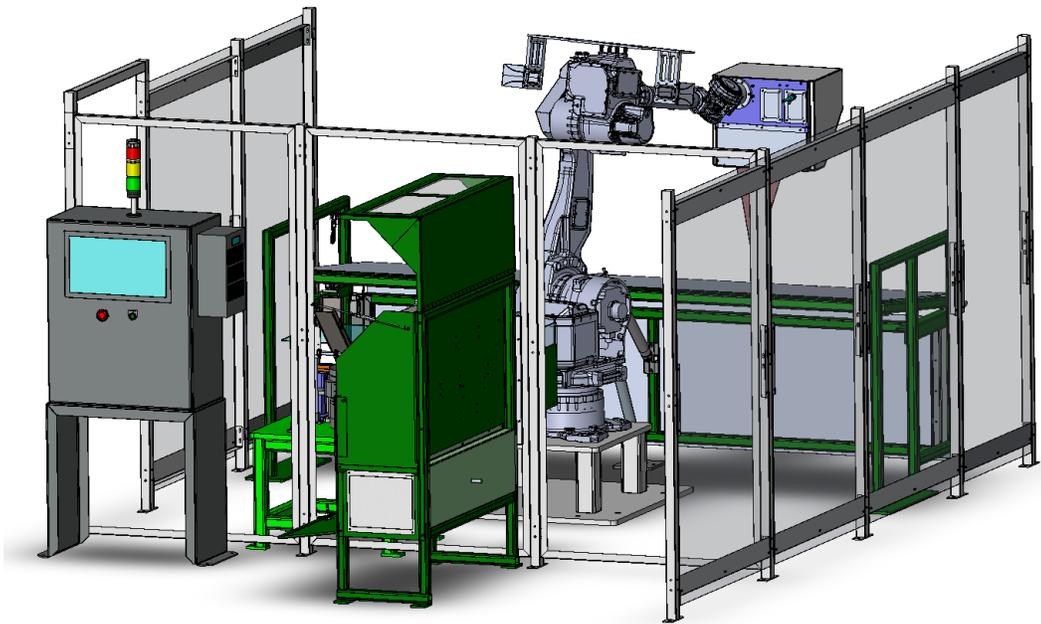


Figure 12 - Position of Operator Interface versus Cell

Project Methodology

One thing that is absolutely essential to every Concept Systems project and a driver for successful implementation is the strict adherence to a standard project methodology. Adhering to each phase of this methodology assures that all our projects will be completed on time, within budget, and to the end customers' satisfaction. The goal of the project methodology is to provide open communications that help everyone involved in the project understand the expectations. When each step is followed, the end result is a system that matches those expectations; in other words, as the customer, you get what you asked for -- a fully documented system that performs to specifications. This methodology represents successful techniques, leveraged from experience, that help to accelerate projects, reduce risk and help assure higher quality output.

An essential deliverable in Concept's project methodology is the Functional Design Document (FDD). The FDD is an understandable, accurate specification defining the requirements and functionality of the system. This is the document that the customer and Concept Systems rely on to outline what a system is required to do. This is the cornerstone document used by Concept Systems for system development. It fully describes the features, functions and capabilities of the system as well as to verify the customer's expectations and responsibilities relating to performance and operation. For this project, Nucor fully embraced the importance of this document and together we went through several revisions of the document. With each revision, there were small improvements made, such as additional precautions to protect the system from radiant heat. By doing this work early in the process and before system development, a smoother startup and commissioning phase is realized with less 'after the fact' modifications being made.

Another part of the methodology is having a 'living' risk assessment document that is referred to throughout the project lifecycle by both the end user and Concept Systems. This is another aspect that was fully embraced by Nucor and helped create a successful deployment of the automated tagging system. The goal of this process is to continually identify and develop mitigation plans with any risks that could impact project success.

Nucor fully embraced the project methodology that Concept Systems' has developed, creating a very strong partnership focused on making the most reliable automated billet tagging system possible. This partnership between an end user and a system integrator (or any vendor) is extremely important in the overall success of any project.

WHERE TO GO FROM HERE

Both the implementation of automated tagging at the caster and the technology described above can be used to make additional process improvements elsewhere in the mill.

Track & Trace

The end game of deploying a system to tag billets is to implement a robust track and trace system that provides mills with actionable information that they can utilize to make better business decisions. Through the implementation of an automated tagging system and a more automated material handling system, mills would be able to use encoder position information on cranes to literally map inventory yards. This information would take tracking product to the next level by deploying solutions and reports, such as real time billet tracking (snapshot of actual inventory), rolling preparation notifications, inventory control report, or other advanced search criteria reports.

Automated Tagging in Other Areas of the Mill

As you probably know, Traceability of product is not limited to billets or slabs coming off the caster. There are many other areas within a steel mill where tagging product is taking place. Many of these areas could likely benefit from technologies that were discussed above. Some of these areas include tagging bundles of product to prepare for shipping, tagging coils or tagging plate product. The vision-guided robotics and welding techniques are just some of those proven pieces of technology that can be used to deploy automated tagging solutions to other parts of the steel mill.

PITFALLS

As with any system, there are potential pitfalls. Since the system consists of a large robot, a good deal of space is required, and once used as part of the robot cell, it makes it somewhat difficult to switch back to hand tagging when issues arise, generally putting the operator closer to the steel beams than they would otherwise be. Secondly, since a steel mill necessarily operate overhead cranes, the weld arc can cause issues with the overhead crane operator's vision due to the weld arc flash. We added a steel flash shield to the end effector to shield the crane operator when plus or minus 30 degrees from overhead, but when the crane is beyond this zone, there is no real shielding possible.

CONCLUSIONS

The process of applying tags to ends of billets, blooms, blanks or slabs is commonplace in today's steel mill. While the technology to automatically print these tags is everywhere, the process and technology of automated attachment is relatively new. The past process of using a manual attachment mechanism creates unnecessary safety risks and potential issues with traceability accuracy. Through the use of vision guided robotics, an extremely reliable automated tagging system can be deployed that mitigates those risks and provides a solid return on investment. The technology that helped make this solution is just a component of the overall success. Although only touched on briefly in the paper, a critical component of the success was the partnership that formed between Concept Systems and Nucor Steel. Concept Systems has established themselves as a premier integrator by taking technology that has been successful in one industry or area and deploying that proven technology to solve different pressing problems through the development of a new game changing solutions. However, these particular solutions could not be nearly as successful without close cooperation from Nucor, a company that live and breathes the steel making process, understanding the improvements required and the risks that may arise during implementation. The partnership formed between Nucor Steel and Concept Systems was essential in the successful deployment of a robotic billet tagging solution. Together, the two companies were able to increase quality through better traceability, increase productivity by freeing up a person to work elsewhere in the mill and reduce overall risk, by improving safety.

REFERENCES

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