Digital Visual Inspection of Coils

M. B. Assar, C. D. Romanauski, M. Kremer, M, Krolikowski, J. Franklin, M. L. Elliott*, R. A. Stankie*

Mittal Steel USA-Cleveland
3060 Eggers Avenue
Cleveland, Ohio 44105, USA
Phone (216) 429.7355
Fax (216) 429.6803
E-mail: mohammad.assar@mittalsteel.com

* Benchmark Automation.
4807 Rockside Road, Suite 370
Cleveland, Ohio 44131, USA
Phone (216) 447-8333
Fax (216) 447-8330
E-mail: rstankie@benchmarkautomation.com

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ABSTRACT:

Visual inspection systems have been widely used throughout the steel industry for detecting defects in coils. A digital visual inspection system was developed and implemented at the Finishing Division Mittal Steel USA-Cleveland. This system is low cost, low maintenance and has been successful in operation as an inspection tool for the last 4 years. This has allowed disposition of coils without incurring additional line inspection and has provided a means to review coils involved in customer claims. It has also been a valuable tool in monitoring mill operations. This paper describes the system, its uses and some of the practical applications.

BACKGROUND

Evaluation of quality problems within mills has always been a difficult undertaking. Quality engineers rely heavily on inspectors to locate defects and report them accurately. When defects are reported, the product is often diverted to re-inspect/rewind lines where quality personnel verify the defects and make disposition on the coil. The process of rewinding and checking is time consuming, causing delays and adds significant costs. Quality problems that are reported back by customers are even more difficult and often impossible to research and resolve.

Similarly, troubleshooting mill equipment problems can also be extremely difficult. Engineers frequently spend large amounts of time trying to find out what actually caused a mill wreck or an equipment failure. Since engineers are not watching each operating unit 24 hours a day, they rely on various tools to help troubleshoot problems. These tools include operator descriptions of what has occurred, strip chart recorders, high speed memory review data, alarm logs, and computer-generated reports.

Video has also become an important tool used to help troubleshoot both strip quality and mill equipment problems. Originally, cameras were installed on mills and video recorded using VCRs. The stored video provided engineers with a method to see what the strip quality actually looked like or to see what really happened on the mill. The problem with the VCR/tape method was that it did not provide the speed or flexibility that was required to quickly resolve mill production and quality problems. Searching a VHS tape, fast forwarding/rewinding, trying to find the desired coil was extremely difficult and time consuming. Many times, the VCR clock had wandered and attempting to synchronize VCR time with the coil-produced time was challenging or impossible. Since the data were stored on tapes, only one person could perform analysis at a time and a dedicated television and VCR were required for the review. There were also a number of annoying maintenance issues that arose with tape storage. The life of VCRs and VHS tapes were limited, especially in a mill environment. VCR heads got dirty and deteriorated VHS tapes resulted in extremely poor image quality. Management of the tapes (changing, labeling, storing) was a nightmare often requiring entire rooms to archive the video for long periods of time. Missing tapes, non-loaded VCRs and powered-off VCRs were just a few more of the problems that existed.

The issues associated with the VCR/tape systems frequently caused them to be more of a problem than a solution. There was nothing more frustrating than spending hours searching through a tape for a specific defect within a coil, only to find that the image quality was too poor to make the images useable.

OBJECTIVES

The objective of the project was to upgrade the existing analog VCR/tape video system to a digital video storage system that would provide the unique functionality required in a finishing mill.

There were two key goals that had to be met. One was to insure that image quality would be excellent and consistent, without degradation. The other was to find the exact location of a defect or questioned area in a coil within seconds, not hours.

In addition to the two key goals, the following features were desired of a new system:

- Flexibility to retrieve images by entering coil number or time-frame
- Allow for images to be stored based on either time, strip footage or mill event
- Provide variable storage rate capabilities for different cameras
- Provide extended storage of critical images for several years
- Provide open interface to mill computers/PLC's in order to incorporate critical mill data into the images
- Allow remote access from any office computer
- Allow simultaneous and multiple user access
- Require little or no maintenance
- Scalable for future camera requirements
- Interface with existing wiring and cameras
- Support high resolution network-based digital cameras for future installations

SOLUTION

All of the VCR/tape systems in the finishing mill were replaced with the state-of-the-art Video Capture System (VCS). This system was designed specifically for steel manufacturing applications. It was developed to have footage-based recording, easy video retrieval by coil number or timeframe, and the ability to overlay critical mill data on the images in real time. Other DVR's (that were actually designed for security surveillance application) offered none of these critical features.

The VCS interfaced easily with the existing analog cameras. This meant no additional wiring had to be installed. The system converts the analog camera signals to digital image files, processes the image files and archives the required images to a hard disk array. The VCS provides two separate networks, one used exclusively for video camera interfaces and the second to interface to the plant network. This architecture insures that 24x7 video traffic does not interfere with the plant network. Management screens provide an easy mechanism to set the different recording rates and archive durations for each camera.

Twelve cameras are currently tied into the VCS system. Two of these cameras are located on the 84" Pickle Line. One Pickle Line camera views the top of the strip while the other views the bottom of the strip. Images are captured from these cameras every two feet of strip during processing. The Pickle Line coil images are archived for a period of four months. Eight cameras on the 84" Tandem Mill were attached to the VCS system. The eight Tandem Mill cameras are setup to view various areas of the mill and are basically used for troubleshooting mill equipment and production problems. These camera images are high-resolution, capturing information at one image per second and retain the images for a period of ten days. Two cameras are located on the 84" Temper Mill. One camera views the top of the strip as it enters the mill while the other views the exit end of the mill. The VCS captures images from the Temper Mill cameras after every five feet of processed strip. These cameras have also been set up to capture an image every two seconds when the mill is not running in order to help troubleshoot equipment problems. The Temper Mill camera images are archived for a period of three months.

The VCS provides many of the tools that are critical for mill troubleshooting. Personnel in any department can access the VCS simultaneously, viewing live or archived images from any cameras at any time. Images are setup to be stored in a manner that best suits the needs of the mill. There is no longer the need to search for the video associated with a particular coil. Personnel simply enter a coil number and view the video, just as one would retrieve a production or quality report. The VCS displays all required information, such as coil ID numbers, line speeds, thicknesses, width, grade, temperature, and mill forces stamped on the images, allowing mill personnel to view critical data along with the video. This feature is critical to troubleshooting mill problems and wrecks. Quality personnel are frequently able to make coil dispositions directly from the video review, reducing reprocessing and improving on-time delivery. Appendix I describes additional details of these cameras.

APPLICATION/RESULTS

Temper Mill System:

Two cameras are currently located on the 84” Temper Mill. One camera views the top of the strip as it enters the mill while the other views the exit end of the mill. Images from each camera are captured every five feet of strip. Figure 1 shows a schematic of the location of camera installation at 84” Temper Mill along with the related network architecture.

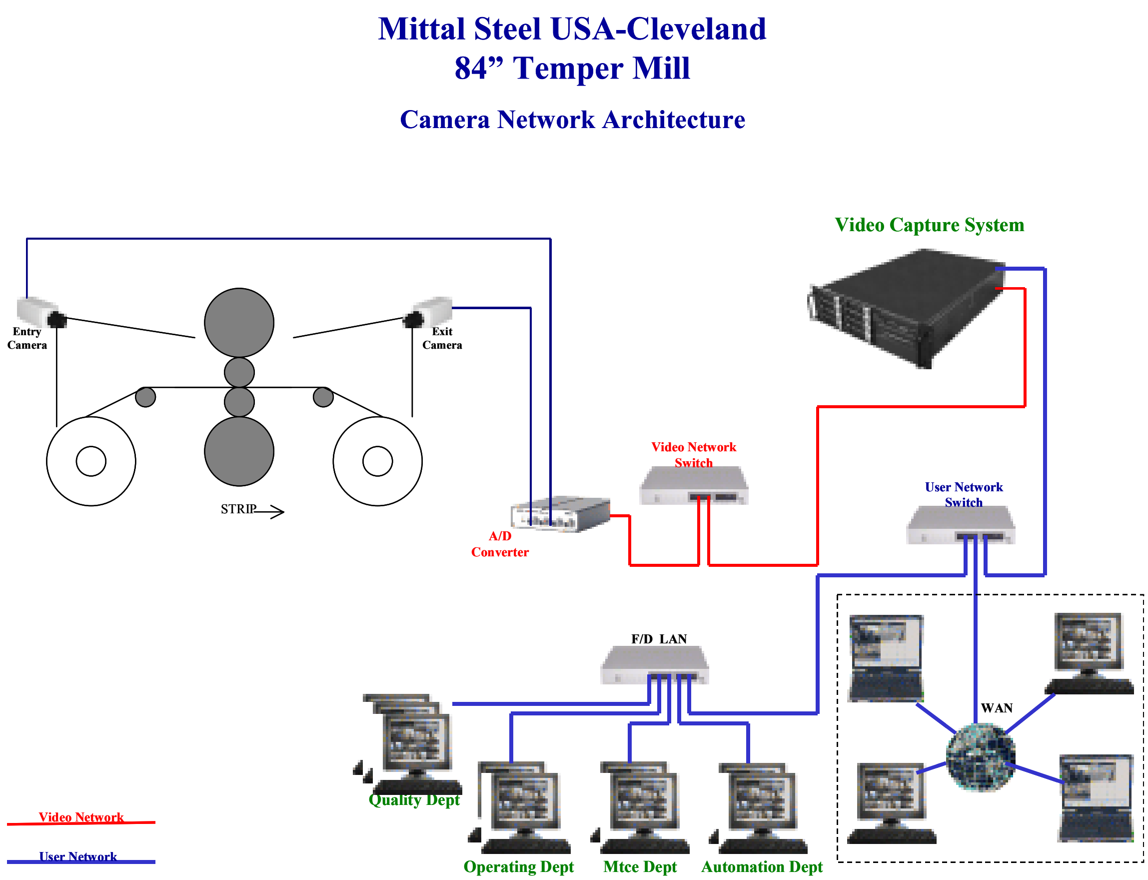


Figure 1 - Location of cameras at 84" Temper Mill and the related network architecture

The VCS system provides an additional set of eyes that monitor Temper Mill operations and strip quality 24 hours a day. Quality personnel now have the ability to go back and view any five-foot section of strip rolled during the previous three months. Coil data are retrieved either by produced coil ID or by selected time frame. The top of each image is imprinted with the incoming and exit coil numbers, footage, line speed and x-ray gauge readout to aid the troubleshooting process.

Figure 2 shows what anyone with network access can see during coil production. Quality engineers frequently review these images to make coil dispositions and investigate customer claims.

Figure 2 - Online/offline production images include parameters like coil number, gauge, speed, footage, etc., making the disposition of the coil much quicker

The ability to make coil dispositions based on review of the images has greatly reduced reprocessing rates on the mill. The video is used to verify reported defects, pinpoint their location, check for additional similar defects, make coil dispositions, and schedule reprocessing. The system has also been extremely effective in investigating/confirming conditions reported by the customer, such as pre-temper mill stain, shape problems and scratches. When a customer makes a claim, they expect an action plan that prevents the problem from occurring again in the future. By reviewing images from the processing of the coil, the source of the problem can frequently be identified and resolved. In the past, there was really no reliable method to investigate customer claims. Resolving coil tracking issues has been perhaps the greatest advantage. Going back and reviewing images along side production records have resolved many misidentified coil issues. Most of the tracking issues are operator/computer input errors or exit end tag errors.

In summary the VCS system has helped in the following areas:

- Acts as a second set of eyes
- Review customer claims
- Troubleshooting mill problems (i.e. mill wrecks, friction scratches, soft incoming coils)
- Product tracking (i.e. coil number verification)
- Live production review from the comfort of the office desk
- Review images for verification at quality meetings
- Unit productivity

Figure 3 - Roller failed to detect the defect, but upon reviewing, the coil image quality inspector identified it

The cameras pick up most conditions that would be visible to the naked eye, but unlike the naked eye, cameras have pause and rewind buttons. The cameras have also detected many operating issues that caused quality problems, which include:

- Friction digs that were the result of improper arbor insertion
- Edge breaks damage that was not repaired prior to temper rolling
- Torn edges and stickers from poor incoming winding
- Mill wrecks resulting from people not reacting correctly to incoming conditions
- Oiler not in position for product (dry up/oiled down)
- Exit saddle left in the up position (responsible for many wrecks)
- Exit table failed to lower (resulting in mill wrecks)
- Creases on the exit reel due to bad start (see figure 6)
- Belt wrapper problems (broken or binding belt)

The live view allows quality personnel to keep track of the status of the mill at any given time with the push of a button. Quality personnel no longer have to rely on operators to notify them when they are needed for trial coils. Delay times, operating practices and roll changes can also be reviewed.

The following two figures exemplify a Temper Mill wreck caused by poor incoming winding. Figure 4 shows the coil being loaded with damaged a sidewall. Figure 5 shows the mill wreck with the coil running at high speed instead of being processed at a lower speed. The coil would have been acceptable if processed at a lower speed.

Figure 4 – Coil is chalk-marked with winding problem as it is loaded

Figure 5 – Coil breaks entering the mill

Figure 6 shows a crease that carried through the entire coil. Review of the video images showed that shortly after the coil entered the belt wrapper, the mill was reversed. This caused the defect to occur throughout the coil.

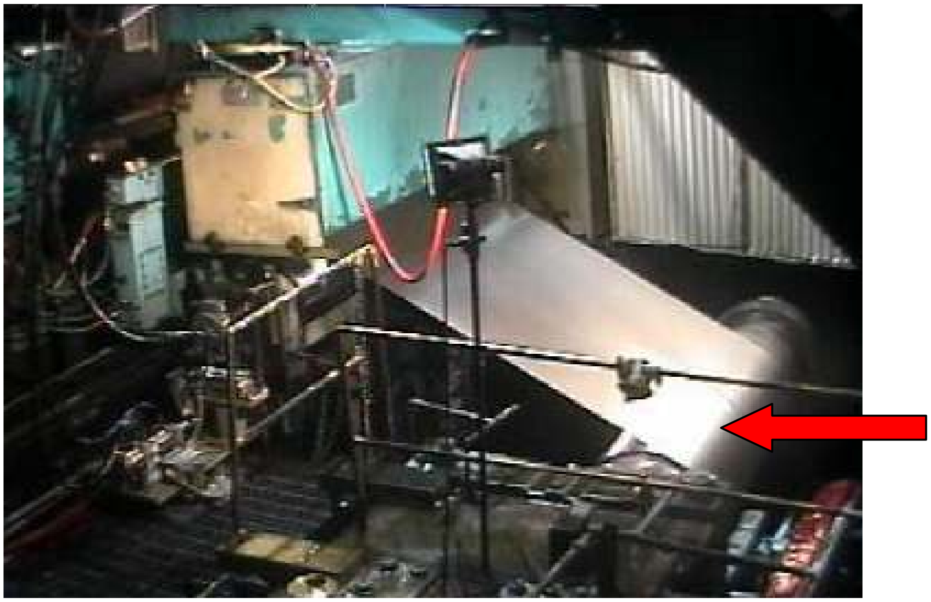


Figure 6 – Mill backed up after belt wrapper came in causing crease that carried through entire coil

Pickle Line System:

Figure 7 shows a schematic of the location of cameras installed at the 84" Pickle Line and the related network architecture. As this figure shows, both the top and bottom surface of coils are being monitored and recorded post acid tanks. The images are stored along with the incoming and outgoing coil numbers as well as the footage and speed.

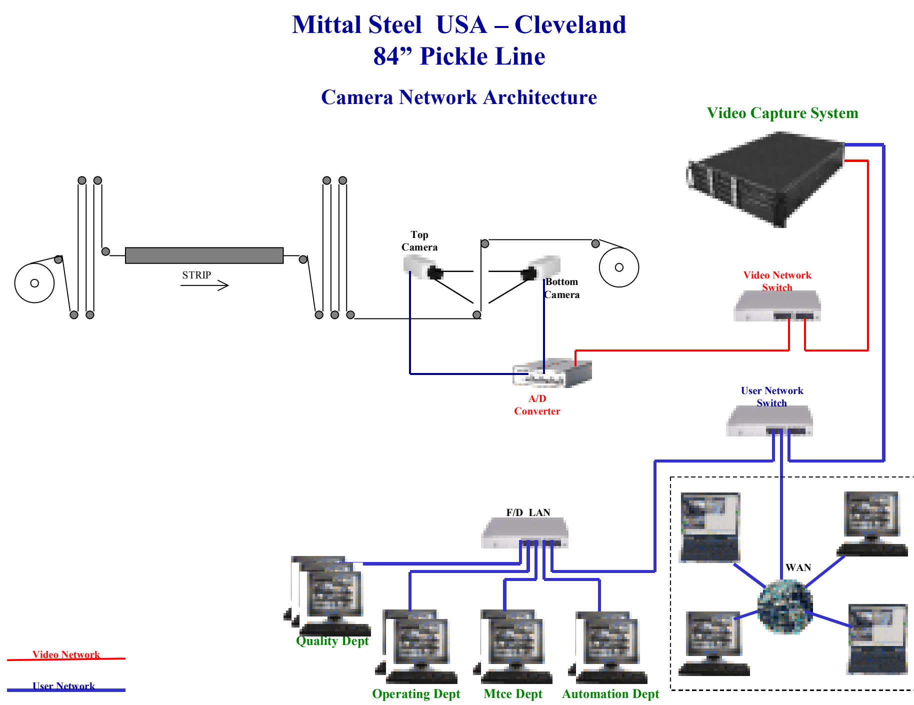


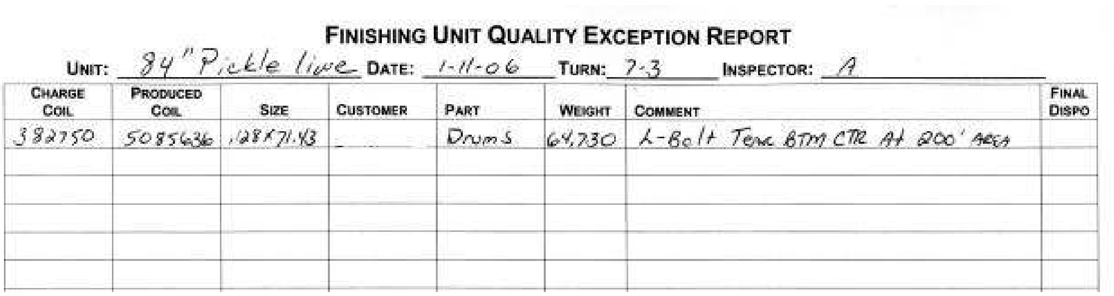
Figure 7 - Location of cameras at 84" Pickle Line

The VCS system for the pickle line is being used in the following ways:

- Inspection aid (second set of eyes)
- Production tracking
- Live review
- Review and print images for quality evaluation
- Weld tracking analysis and verification

Utilizing the inspectors' comments and the video images, personnel have the ability to identify and disposition a class of defects that would be detrimental to future units or customers. Disposition may include coil rejection. Another possible disposition is to process the coil with a feed forward note to alert future units about the defective areas for potential removal in either small coils or blank forms. Other software programs have also developed that simplify the identification of defective locations by calculating their positions after the coils have been cold reduced, including edge and footage locations.

As with the Temper Mill system, benefits are received trough production tracking and live review. In most cases, the printed image of a defect satisfies the visual need for confirmation. The example below shows the inspectors report in comparison to the actual video image.



FINISHING UNIT QUALITY EXCEPTION REPORT

UNIT: 94" Pickle line DATE: 1-11-06 TURN: 7-3 INSPECTOR: A

CHARGE COIL	PRODUCED COIL	SIZE	CUSTOMER	PART	WEIGHT	COMMENT	FINAL DISPO
382750	5085636	.128X71.43	–	Drums	64,730	2-Bolt Tear BTM CTR At 200' Area	

Figure 8 - Inspector reports indicating possibility of a defect on one coil

After reviewing the inspectors comments, the video image confirms the severity of the defect, but shows the defect actually occurred at 98 feet.

Figure 9 - The image of the suspected coil was reviewed and the exact location of the defect was found

Knowing the position of the defect in the pickled coil, the future units operator can maximize production by running at a higher speed until the defect arrives, then slows down to look for the defect. A simple Excel program was developed to calculate the defect location. Figure 10 shows a sample spreadsheet. This program calculates the defect position, as it would appear post temper pass. It enables the re-inspection unit to go directly to the noted footage running at a normal speed of 800-900 feet per minute (fpm), eliminating the need to run the entire coil at re-inspect speed, which is 315-350 fpm.

CURRENT LOCATION OF PICKLER DEFECT

LOCATION OF DEFECT AT PICKLER	
EAST/WEST (E/W)	W
TOP/BOTTOM (T/B)	B
FEET FROM WELD	2050
TANDEM MILL COIL NUMBER	5197453
TANDEM MILL ENTRY GAUGE	0.1105
TANDEM MILL EXIT GAUGE	0.0298
TANDEM MILL COIL LENGTH	9399
CALC PKL COIL LENGTH	2535
CURRENT DEFECT LOCATION	
FEET FROM CURRENT OD	**1516**
CURRENT TOP/BOTTOM	**B**
LAST UNIT EAST/WEST	**E**
CURRENT LEFT/RIGHT	**L**

	Y/N	Entry Reel Orient-ation	Delivery Reel Orient-ation
PKL	Y	O	O
TCM	Y	O	O
SLTA1			
SLTA2			
SLTA3			
TMP1	y	O	O
TMP1		O	O
SLTB1		O	O
SLTB2			
SLTB3			
TMP2		O	O
TMP2		O	O
SLTC1			
SLTC2			
SLTC3			

Notes:
1. Does not acount for coils run on Slitter after Pickler, before Tandem Mill
2. Assumes 3% scrap loss from Temper Mill entry pup and that this is Pickler tail
3. Assumes no scrap loss at Tandem Mill or Temper Mill prep shear

Figure 10 - Pickle Line Defect Spreadsheet

Figure 10- A typical Excel spreadsheet used to predict the location of defects at different locations, knowing the position of defects in the pickled coil. The yellow shaded fields are filled in and the software does the rest. The slitter operator would know to slow down at 1516 feet from the outer and the defect would be on the bottom east or left edge of the strip

Weld Tracking Analysis & Verification:

Figure 11 is an example of a pickle-weld and punched hole that is detected at the Tandem Mill identify the correct point to split coils. Occasionally, the weld was not detected and was processed through the Tandem Mill, resulting in roll mark and premature roll change.

After installation of VCS, engineering personnel analyzed the video images containing the affected strip footage and saw that an occasional weld did not have a punched hole. Maintenance personnel corrected the problem at the punch and verified the reliability at the weld tracking at the Tandem Mill. This investigation resulted in savings by reducing the number of roll changes at Tandem Mill and eliminated reprocessing costs.

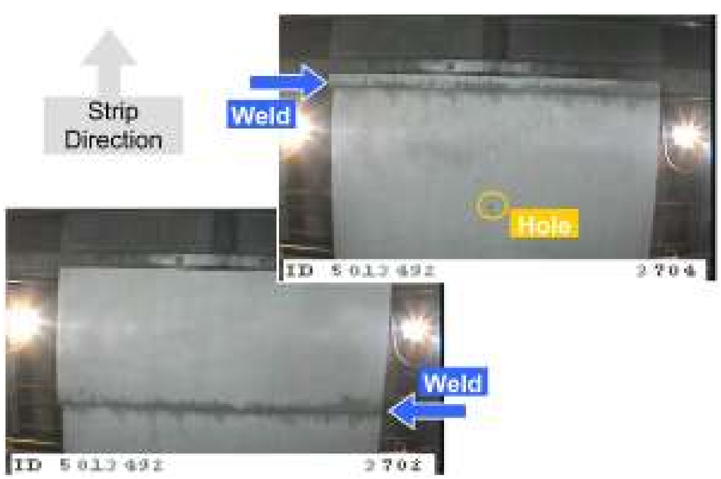


Figure 11 – Pickle weld with hole used for tracking

Tandem Mill System:

Figure 12 shows a schematic of the location of camera installation at 84" Tandem mill along with the related network. There are eight cameras installed on the Tandem Mill. The system is being used for monitoring the mill operation and performing wreck analysis.

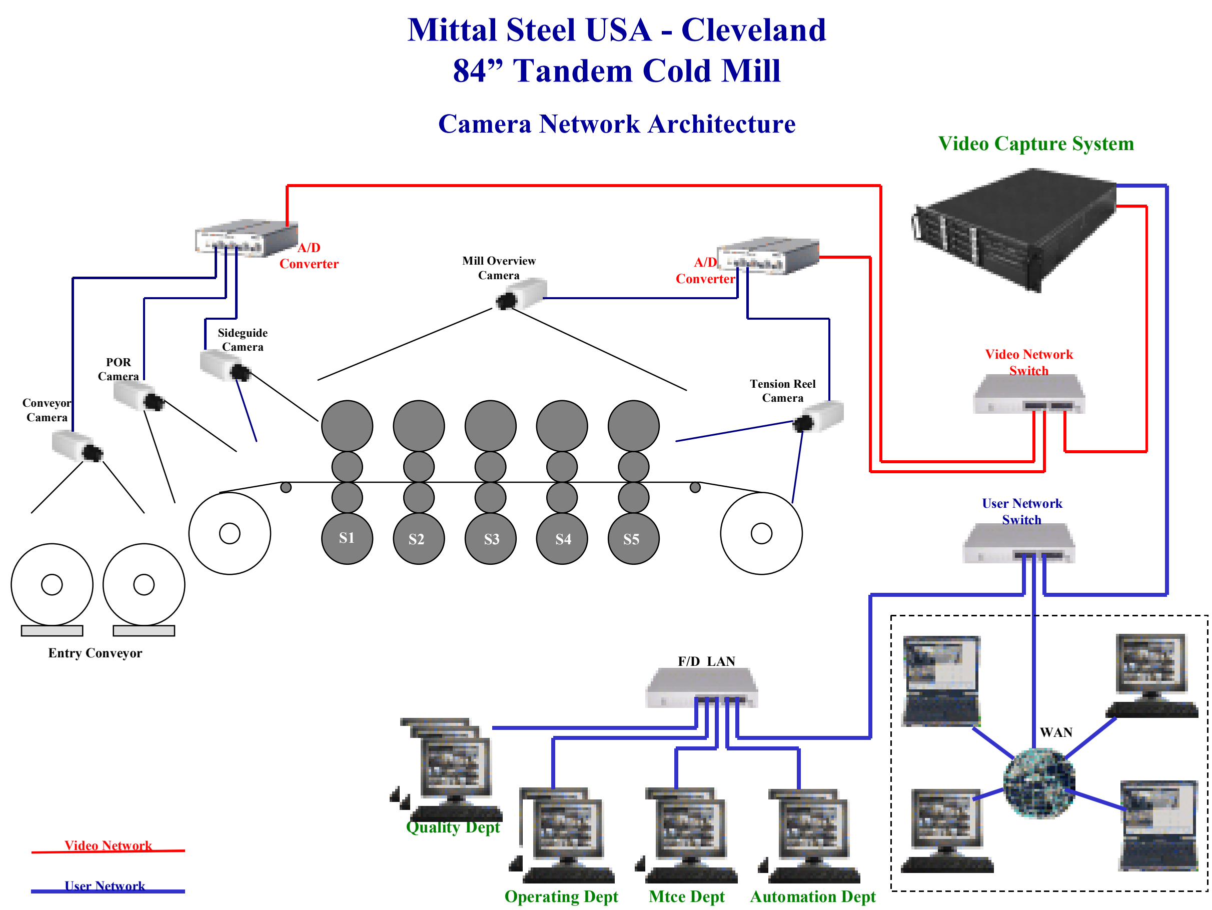


Figure 12 - Location of cameras at 84" Tandem Mill and the related network architecture

Numerous problems have been resolved using the VCS system. The following two pages describe two problems.
A coil falling into the pit raised safety concerns regarding proper functionality of the equipment. The coil was being moved from the tension reel to the exit conveyor. No one saw what happened, so the cause was not known. Figure 13 shows the coil movement, tailing out, mandrel collapsing and coil being removed from the tension reel with a loose flap.

Figure 13 – Normal removal of coil.

Figure 14 has three pictures, the first two showing normal movement. The third picture shows the buckle catching on the conveyor pad.

Figure 14 – Buckle hitting the conveyor pad

Figure 15 shows the transfer car moving the coil towards the exit conveyor. The conveyor pad stops the coil. As the transfer car moves, the coil starts to slide off the transfer car and fall into the pit.

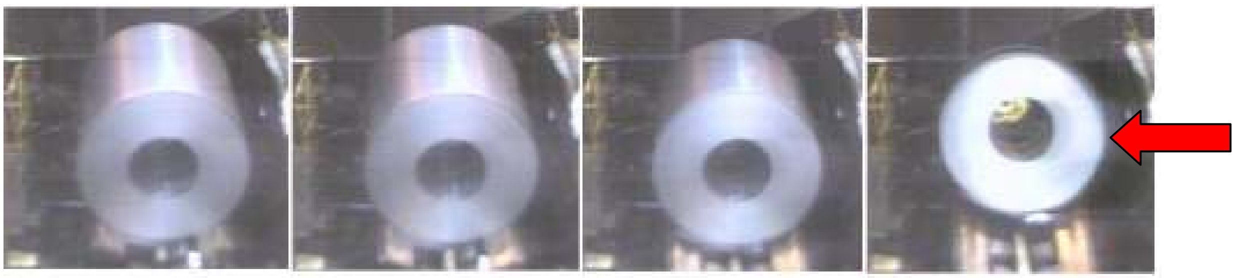


Figure 15 – Shows the coil sliding off the transfer car and falling into the pit.

The images above showed the equipment was operating properly, saving investigation time of a non-existent mechanical, electrical or safety problem.

Another example involved unexplainable stand #1 wrecks that were occurring two to three times per month. Review of the VCS video after one such wreck showed that during mill delays, the uncoiler would slowly rotate forward, loosening the laps and causing the coils to telescope due to loose tension.

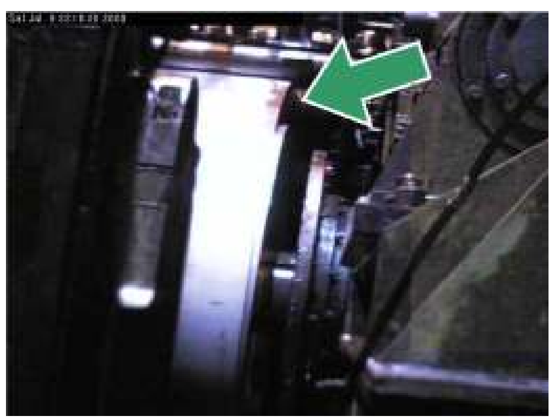


Figure 16 – Incoming coil is wound tight without telescoping.

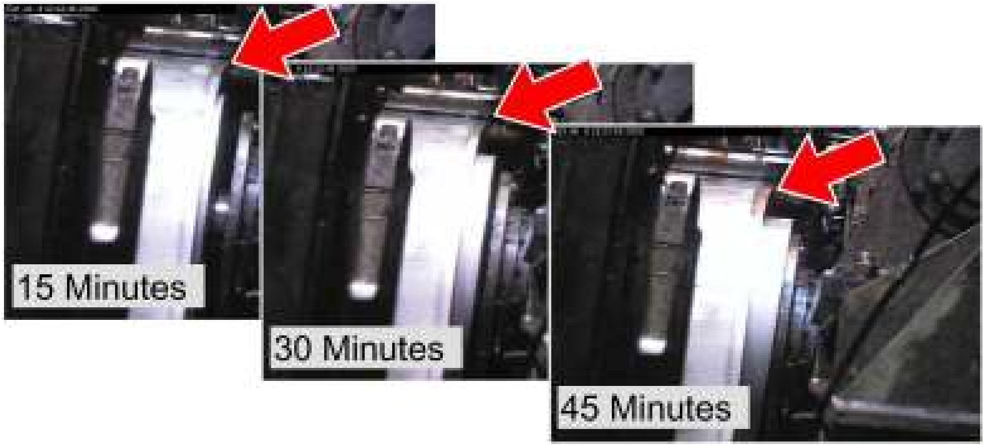


Figure 17 – Uncoiler drifts forward causing coil to loosen and telescope.

When the mill would re-start, the arbor centering system was unable to compensate for the severe telescope resulting in the strip going over the sideguides and causing a wreck. Maintenance personnel reviewed the video and traced the cause to out-of-adjustment brakes on the uncoiler motors. The brakes were repaired and the stand #1 mill wrecks were virtually eliminated.

CONCLUSIONS

The VCS was installed at the Finishing Division - Mittal Steel USA-Cleveland in 2001. The system is being used successfully for wreck analysis, troubleshooting, coil quality evaluation, claim review, and production tracking. Significant savings have resulted since video investigation was implemented. The number of reprocess coils as well as the number of mill wrecks has been greatly decreased. Improvements in the following areas have also been attained:

- Increase productivity
- Improved yield
- Reduced maintenance costs
- Quality, production and engineering personnel are more efficient in their troubleshooting techniques
- Downtime has been reduced

Appendix I
(Details of Camera)

Cameras are installed throughout the finishing department. The following describes the camera locations and how our product is visually tracked:

Production Unit	Location	Image Capture Rate
84” Pickle Line	Top of Strip	Every 2 feet
84” Pickle Line	Bottom of Strip	Every 2 feet
84” Tandem Cold Mill	Entry Conveyor	High Resolution @ 1 image/second
84” Tandem Cold Mill	Uncoiler	High Resolution @ 1 image/second
84” Tandem Cold Mill	Entry Holding Shelves	High Resolution @ 1 image/second
84” Tandem Cold Mill	Stand 1 Right Sideguide	High Resolution @ 1 image/second
84” Tandem Cold Mill	Stand 1 Left Sideguide	High Resolution @ 1 image/second
84” Tandem Cold Mill	Stand 1 Roll Bite	High Resolution @ 1 image/second
84” Tandem Cold Mill	Tension Reel	High Resolution @ 1 image/second
84” Tandem Cold Mill	Mill Overview	High Resolution @ 1 image/second
84” Temper Mill	Mill Entry	Every 5 feet when running and every 2 seconds when not running
84” Temper Mill	Mill Exit	Every 5 feet and every 2 seconds when not running
Slitter Line – future	Strip Surface	High Resolution camera for strip inspection

Appendix II
Details of the VCS System

The Video Capture System (VCS) is a state-of-the-art digital video recording system. Images from cameras placed throughout the steel mill are used for troubleshooting numerous types of problems. Whether the cameras are analog or IP/digital, the VCS has ability to store the images for weeks, months or even years. Images from an IP/digital camera are in a motion jpeg format. Analog video signals are inputs to an A/D converter.

The VCS is network-based. This means that any computer using a standard web browser or the VCS Client software is capable of connecting to a network (Intranet or Internet) and displaying live and archived images.

One key feature of the VCS is the open interface, which allows production computers (Level 1 or Level 2) to have easy control the VCS via a wide array of messages. The messages sent to the VCS contain key information (heat/bar/slab/coil) ID numbers and relative process data (footage, width, thickness, speed, temperature and any other critical process data) as production occurs. All of this information is linked with an image and stored for easy retrieval.

There are a number of other features the VCS can provide:

- Create multimedia reports that visually explain what happened
- Include process images in email, reports, and studies
- Use images or 'movies' for operational and safety training
- Use remote Pan-Tilt-Zoom control from any internet-enabled computer to position cameras
- Create a time lapse "video" of any archived images (JPEG or MPEG)
- Unlimited user access to troubleshoot various problems at the same time

The flexibility of choosing the right camera for the job is also critical. The VCS is designed to easily integrate with many different camera manufacturers. It also allows for multiple types of cameras, such as, analog, IP digital, wireless, high-resolution mega pixel and pan-tilt-zoom cameras, which are all integrated into one system. The VCS Client software shields the users from differences between the camera types.

The VCS is based on a unique concept of total images per second (ips). For example, we can choose to utilize 400 ips in different ways. There can be 100 cameras recording 4ips, or 400 cameras at 1 ips, or any other combination. Critical camera images can be stored for longer periods of time and at a higher frame rate, than those of less critical cameras. For example, images from a camera pointed at the exit of a mill are saved for months for quality reasons. Images from cameras pointed between stands could be saved for 5 or 7 days, enough to troubleshoot cobble or off-level mills. This concept also allows for only one system being needed compared to multiple 16-port DVR solutions when 17 or more cameras are installed.

There are three VCS rack mount servers that are available; an 8, 16 and 24 disk drive system. Each VCS is customized for each application, based on a number of parameters: total number of cameras; image/second capture rate; storage length; percent recording activity; and future expansion plans. A VCS requiring 12 disk drives will have 4 spare slots in the 16 disk system, and 12 spare slots in the 24 disk system for future cameras or increased capacity.

In addition to the applications mentioned in this paper, Benchmark Automation has also developed additional applications to meet the changing requirements of the mill environment. The installations include most areas of steelmaking, from primary operations to hot and cold rolling. The applications include production monitoring, slab surface, cobble, off-level mill analysis, emissions monitoring, safety compliance, and security surveillance.