Weigh Measure Stencil Systems for Tube Mills

David L. Anderson
InfoSight Corporation
20700 State Route 23
Chillicothe, OH 45601
Tel: (740) 642-3600
Fax: (740) 642-3777
E-mail: dla@infosight.com
Web Site: www.infosight.com

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INTRODUCTION

Tube manufacturers are required to accurately measure, record and tally tube weights and lengths for their own records, and for their customers. They are also required to mark the tubes with certain stencil identification, stamped identification and colorband markings. These markings provide identification and traceability for the product, enabling the manufacturer and the end-user to verify the "pedigree", or manufacturing history of each tube.

This paper discusses the evolution and operation of equipment to weigh, measure and identify tubes in the steel mill, typically called "Weigh Measure Stencil Systems" or simply "WMS Systems".

HISTORY

In past years, measuring and marking systems for tube were typically crude manual operations. It was not unusual to visit a tube mill and see length measurement being performed on a tube-by-tube basis by two workers with a tape measure. Tube weights were manually recorded from weigh scales adapted from truck scale designs. Stenciling was typically sprayed or rolled on the tube using custom-cut stencil mask boards, with workers later filling in tube-by-tube length and weigh information as it could be sorted out from the paperwork. Record keeping and tallying of tube weight and length totals was done by hand on paper forms.

Human errors occurred often, and the measuring-and-marking operation was the bottleneck of the tube manufacturing process. The output of the tube mill depended on how fast the workers could manually weigh, measure, mark and tally the tubes. Errors increased as pressure was put on the workers to get the product marked and out the door.

Islands of automation started to appear, with unique solutions for automatic length measurement and automatic stencil being implemented at many plants. Totally integrated solutions for measuring and identification were not readily available to the industry.

In the late 1970s, the price of crude oil was high, and the tube marketplace was booming. Tube manufacturers were filling orders as fast as they could ship bundles out the door. Unfortunately, the measuring and marking processes described above limited this output. The industry was clamoring for an automated solution to the bottleneck. At that time, a few companies around the world responded by inventing automated systems to automatically weigh each tube, automatically measure the length of each tube, and automatically mark each tube. These systems evolved to automatically generate reports documenting the identification marked on the tubes, as well as reports that automatically totaled tube length and weight production. In the tube mills where these automated systems were installed during this boom period, production records for "per turn", "per day" and "per week" output were shattered, and worker incentives increased dramatically.

This was the birth of the automatic Weigh Measure Stencil Systems in use today.

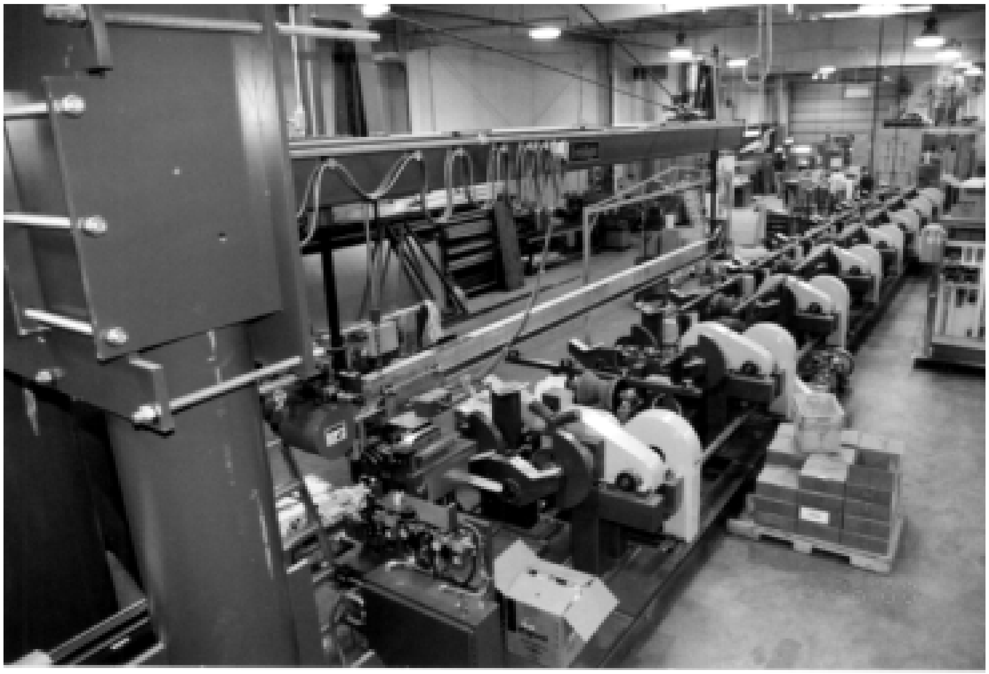

Figure 1 Cross transfer walking beam WMS system

GENERAL CAPABILITIES

A Weigh Measure Stencil (WMS) System generally offers the following minimum automatic capabilities:

- Weight Measurement
- Length Measurement
- Stenciling
- Report Generation

In addition, the following optional automatic capabilities may be needed, depending on the specification of the product being produced, or special customer requirements.

- Stamping
- Color banding
- Bar Code identification

WMS GEOMETRIES

WMS systems are configured to a user's existing process flow geometry and passline elevation. Almost every installation is unique, and some custom design is required. However, in general, the two categories of WMS geometries are "in-line" systems, or "cross transfer" systems.

In-Line WMS Systems

In-line WMS systems typically make use of the user's existing tube conveyors to move the tube during length measurement and stenciling. A typical in-line plan layout is shown in Figure 2 below.

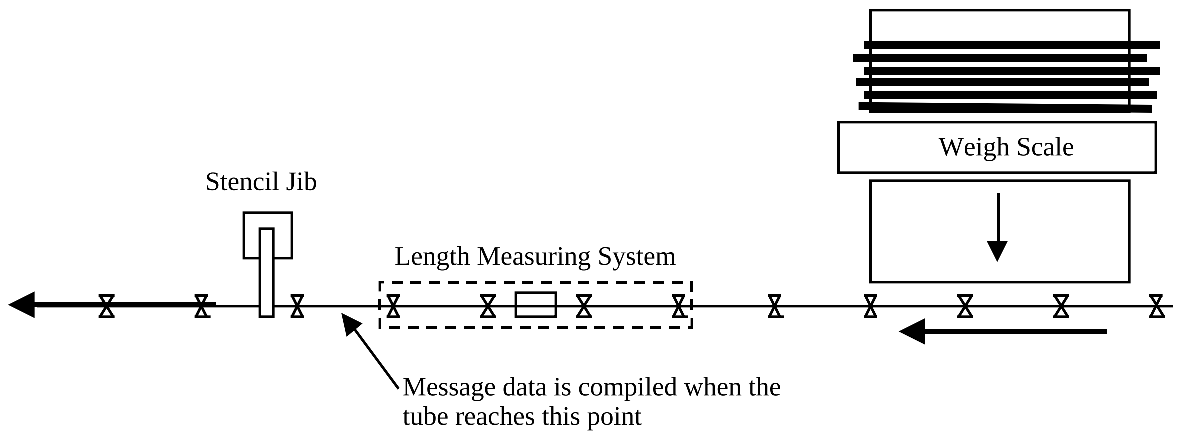

Figure 2 Typical in-line WMS plan layout

Typically, weighing of a static tube is performed at an upstream weigh scale. The captured weight is stored in a software FIFO (first-in first-out) queue, with each queue weight compiled later into the message data when the tube reaches the marking station.

Length measurement is performed as the tube moves in the conveyor. An encoder roll contacts the tube surface and measures the displacement of the tube in pulses per unit length. Sensors are provided to (1) control the operation of the encoder roller, and (2) sense passage of the leading end and trailing end of the tube. In some cases, multiple trailing end-of-tube sensors are provided. By knowing the exact offset distance from the leading end sensor to the trailing end sensor (or sensors), and the number of encoder pulses collected, the length can be calculated.

Other types of in-line length measurement are also available, such as paired high-density optical arrays that do not require encoders, and laser doppler velocimeter systems.

Length accuracy in high-speed, say 0.5 to 1.5 mps (100 to 300 fpm), in-line applications is typically easily guaranteed at API[1] tolerance of ±30 mm (0.1 foot). Accuracy can be increased by (1) decreasing conveyor speed, and/or by (2) using multiple upstream end-of-tube sensors, each with its own offset distance from the leading end of tube sensor. Use of multiple end-of-tube sensors greatly decreases the portion of the tube length that is measured by encoder, and therefore reduces cumulative errors due to slippage, encoder roll wear, etc..

The captured length value is stored in a software FIFO queue, with each tube's queue length value to be compiled into the message data when the tube reaches the marking station.

It is usually not standard operating procedure to remove tubes in process between weight and length measurement and stenciling, in order to prevent corruption of the queue data order and therefore incorrectly marked tubes. An editable queue function is provided to facilitate queue editing in the event of tube removal.

[1] API – American Petroleum Institute

When both the length and weight have been captured for a given tube, the WMS software performs a tolerance check of weight to length by comparing the actual weight to the actual length and by knowing the theoretical weight per foot. If the comparison falls outside of allowable tolerances (typically +6.5%/-3.5% for API), the tube is automatically marked as a reject. It is possible to adjust for couplings and end protectors in the length and weight measurement and in tolerance checking. A length range check is also performed, to confirm the tube length falls within an allowable min/max length range as ordered by the customer.

If either the weight- or the length-measuring system is temporarily disabled, it is possible to configure the WMS system to calculate the disabled system value, by knowing the tube weight per unit length. However, tolerance checking cannot be performed whenever either the length- or the weight- measuring process is disabled.

After length, weight, tolerance check, and length range check, the message is "compiled" or assembled, by combining the measured weight, the measured length, and either the good or reject stencil data into one message for stenciling on the tube. (Note that it is possible to program the compiled reject message to omit length and weight).

Stenciling is performed as the tube moves in the V-roll conveyor. For applications with U-roll conveyors, centering pinch rolls are required to center the tube for marking.

The tube approaches the stencil jib and sensors sense the tube's passage. The stencil jib lowers the marking head, and marks the compiled message onto the tube. The marking head rises at completion of marking. A safeguard sensor is provided, so that if the trailing end of the tube approaches the marking head before marking is complete, the head will abort and rise to prevent damage to the equipment.

Color banding is not readily adapted to in-line systems unless there is a station where the tube can be stopped, end-indexed, and spun by spin rollers. Stamping also is not readily adapted unless there is a station downstream of the weighing and length measurement operations where the tube can be stopped in an end-indexed position in a V-saddle station.

The sequence of WMS processing is significant - marking of "logo" product (for example, marking of product that certifies the product conforms to a given API specification) should not be performed until after all weight measurement, length measurement, and tolerance checking is performed and is confirmed to be within specification.

Cross Transfer WMS Systems

Cross Transfer WMS systems are typically required by existing user process geometry to process tubes as they transfer laterally through the system. Transfer mechanisms used to transfer tubes from station-to-station are typically walking beams, paddle arms or lever arms.

The sequence of WMS processing is generally length, weigh and stencil for minimal systems. For fully capable systems, the typical sequence is length, weight, colorband, stencil and stamp.

Refer to Figure 1 for a picture of a complete typical cross transfer WMS unit. A cross section view through a typical walking beam cross transfer WMS unit is shown in Figure 3 below.

Length measurement is performed on the tube in a set of idle rollers. An encoder roll contacts the tube surface and measures the displacement of the tube in pulses per unit length. A pusher cylinder pushes the tube through an array of sensors, while the encoder measures the tube movement. Sensors are provided to sense (1) the near end of tube at the fully pushed position and (2) the far end of tube as it passes multiple sensors. By knowing the exact offset distance from the pusher end sensor to a given far end sensor, and the number of encoder pulses collected, the length can be calculated.

Depending on circumstances, other types of in-line length measurement can be used, such as traveling carriages to "find" the far end of an indexed tube, and laser distance measurement devices.

The described length measurement system for cross transfer systems is a low speed system. Length accuracy is typically guaranteed at a tolerance of ±10 mm (~0.4 inch). Accuracy can be increased by more precise sensor position calibration and tight sensor aperture control, to +/-2 mm (~0.08").

The captured length is stored in a software FIFO queue, with each queue length value compiled later into the message data when the tube reaches the marking station.

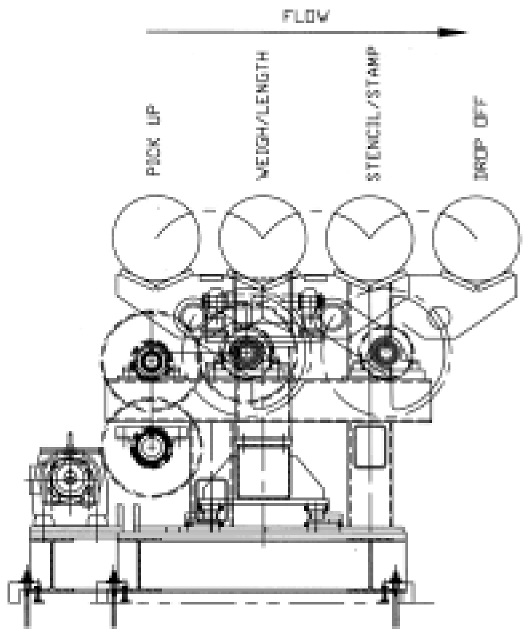

Figure 3 Typical cross section through walking beam WMS system

Weighing of a static tube is performed on a weighbridge supported on load cells. The captured weight is stored in a software FIFO queue, with each queue weight compiled later into the message data when the tube reaches the marking station.

If cycle time permits, it is sometimes possible to combine both length and weight measurement into one process station (as shown above), whereby the tube weight is obtained first, and the tube is then pushed on idle rolls at the weighbridge station to obtain the length.

In the same fashion as for in-line systems, when both the length and weight have been captured for a given tube, the WMS software performs a tolerance check of weight to length by comparing the actual weight to the actual length, knowing the theoretical weight per unit length. If the comparison falls outside of allowable tolerances, the tube is automatically marked as a reject. Again, it is possible to properly adjust for couplings and end protectors in the length and weight measurement, and tolerance checking. A length range check is also performed, to confirm the tube length falls within a preprogrammed allowable min/max length ordered.

In the same fashion as for in-line systems, if either the weight- or length-measuring system is temporarily disabled, it is possible to configure the WMS system to calculate the disabled system value, by knowing the tube unit weight. However, tolerance checking cannot be performed whenever length or weight measuring is disabled.

After length, weight and tolerance check, the message is “compiled” or assembled, by combining the measured weight, the measured length, and either the good or reject stencil data into one message for stenciling on the tube. (Note that it is possible to program the compiled reject message to omit length and weight).

For systems with an optional colorband station, the tube is spun on a series of motor-driven spin rolls at a fixed rotational speed. Color band nozzles are located at the correct longitudinal positions for marking, and are plugged into their respective colors using a switchboard-type plug-in panel. Each nozzle sprays through a slotted mask to set spray band width. Duration of spray is matched to tube diameter. It is possible to colorband the tube according to the “good” or “reject” status of the tube.

Stenciling is typically performed on the top dead center of the tube, and stamping is generally performed on the bottom dead center of the tube. This geometry permits both operations to be performed concurrently at a common station. If separate stations are required, then both stenciling and stamping are performed on the top dead center of the tube.

Stenciling is performed by lowering a marking carriage to bear on the top of the tube with a contact roller, and then traverse a marking head longitudinally to mark the stencil message along the tube's axis. Stencil character height can vary by user preference but is typically 32 mm (1.25 inch) high. The type of marking head used can also limit the height – for example, certain ink jet printers can mark a near-typeset quality mark with 48-dot high resolution, however the character height is limited to a maximum of 19 mm (0.75 inch), and marking speeds are limited. Drop-on-demand marking heads can typically print 16-dot high resolution up to 67 mm (2.6"). Other technologies can mark larger characters if required. Specialized logos can be marked in dot matrix form, such as the manufacturer's company logo, or industry-required logos such as the API logo.

Stamping is performed by an X-Y articulating pin cartridge. The pin cartridge typically is equipped with ten (10) pneumatically driven conically pointed pins, which are fired to indent the tube surface with "dots" to form dot matrix characters. Up to 4 characters are marked per pin, resulting in a total message length of 40 characters. If cycle time permits, up to two rows of 40 characters are possible. Typical character height ranges from 6 mm (0.25 inch) to 10 mm (0.38 inch). Dot matrix character density typically ranges from 5x7 to 7x9 (width x height), with higher densities possible. Custom marking head configurations are possible.

OPERATION

A typical operating sequence for a cross transfer WMS System (including stamping) is discussed.

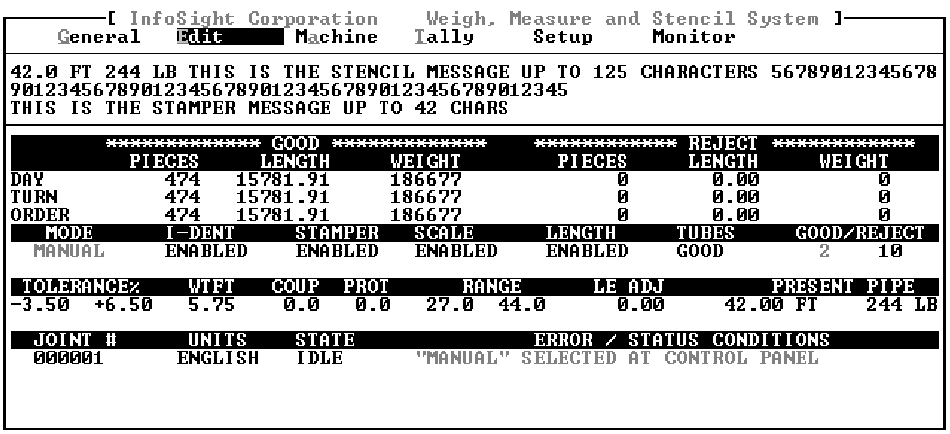

Figure 4 Typical main operating window of the WMS system

1. The Operator performs the following operations prior to processing tubes, via the Main Operating Window shown in Figure 4 above:
   - select a message buffer
   - set a "name" for the buffer for easy future reference
   - setup stencil and stamper message formats
   - setup automatic joint sequential numbering, if enabled
   - setup ± weight tolerance percentages
   - set the tube unit weight per foot
   - set the coupling weight, if needed
   - set the protector weight, if needed
   - set the allowable length range
   - set the length end adjustment factor

   Normally the message buffers will be setup far in advance of operation by a supervisor with knowledge of upcoming orders.
2. The Operator selects the good and reject message buffers to be used for this production run of tubes.
3. The Operator edits the good and reject message data content, if required.
4. The Operator enters the header information to be printed on the Tally Report and the Production Report.
5. If it is desired to clear any of the screen totals prior to starting operation, the Operator clears any of the totals for day, turn, or order. (Note that user may specify different total fields than those shown, for example, bundle or car.)

6. The Operator selects auto mode and enables the WMS system for auto operation.
7. When a tube is presented at the pickup position, it will be the first tube to be processed. If a tube is present at the dropoff position, the machine will not cycle, as the system interprets this condition as the exit table being full and unable to receive additional tubes.
8. The automatic sequence then proceeds as follows:
    a) The walking beam cycles and the tube at the pickup position is walked to the length / weigh station.
    b) As the walking beam lowers, the tube settles into the Length / Weigh station idle V-rolls. A sensor signals the tube is in position.
    c) The weigh scale allows a 3 second settle time, and then the tube is weighed.
    d) Following weighing, the index cylinder extends fully to end index the near end of the tube. The far end of the tube passes sensor “n” (where “n” is one of the multiple “away” length sensors) during indexing. When the near end of the tube passes the length home sensor, length is calculated using the known fixed distance from the home sensor measured to sensor “n” and the known distance of travel calculated from the encoder pulses.
    e) If the Operator wants to arbitrarily reject the tube coming into the stencil / stamp station for any reason, he can press a reject button at any time during the walk cycle from length/weigh to stencil/stamp.
    f) Upon receipt of the length and weight, the system performs the weight tolerance check and length range check for the tube just arrived at the stencil station.
        i) If a weight tolerance error occurs, the system stops and waits for the operator to declare continue or to declare the tube as a reject.
        ii) If a length range error occurs, the system stops and waits for the operator to declare continue to declare the tube as a reject.
        iii) Note it is possible for the system to notify a weight tolerance error immediately followed by a length range error after the weight tolerance error has been acted upon by the Operator.
    g) If the tube is declared a reject (either arbitrarily, or by tolerance error or length error), the preprogrammed reject message buffer for Stencil (only) will be printed on the tube. If the tube is declared good, the preprogrammed good message buffer for both Stencil and Stamp will be printed on the tube, as follows:
    h) After weight and length measurement, the walking beam cycles and the tube is transported to the stencil / stamp station, while at the same time, the tube at pickup is transported to the length / weigh station.
    i) The stencil carriage lowers onto the top surface of the tube.
    j) The stencil carriage moves while marking the stencil data onto the tube. The fixed height stamper head will simultaneously stamp the underside of the tube. When both the stencil and stamp operations are complete, the stencil head will rise.
    k) The tube at the pickup station will advance to the length / weigh position, and the tube at the stencil / stamp station will advance to the dropoff position. Note that if the dropoff sensor stays on constantly after tube exit, the system interprets the condition as a full exit table. The system will halt until the exit table clears.
    l) The Operator may at any time:
       - Print a Production Report (tube-by-tube record of production with time stamp)
       - Print a Tally Report (totalized report of messages printed with GOOD and REJECT totals)

BAR CODES

There has been some progress in the application of bar codes to tubes in the steel mill environment, but the limiting factors remain:

- How to apply a bar code that survives the process and remains machine readable
- How to “find” the bar code at downstream reading locations

Two successful tube bar coding applications are presented.

Bar codes on tube OD

In the first application, text information and a large (approximately 107 cm long x 5 cm high (42” long x 2” high) binary bar code is applied to the outside diameter of large OD API Specification 5L tubes by a dot matrix stencil marker. The height of this code gives a good chance for survival and high percentage readability downstream. This code enables approximately 2 million unique piece identification numbers or PINs. This code is repeated the full length of the tube at a known repeat distance, which enables downstream reading systems to have an adequate field-of-view to view at least one code on the tube as the tube is rotated in various process and inspection spin stations. See Figure 5 below.

The enemy of tube OD bar codes is any process that can deface the code. It is required to get at least one horizontal scan line through the complete length of the bar code without loss of any bars due to defacing. Removal of a given bar by scraping, roller friction, grease, etc. can render the code unreadable. However novel video-based bar code reading solutions are provided to “stretch” damaged bars vertically to electronically fill-in defects and provide a good read.

Large diameter tubes are obviously less prone to damage because there is less process contact per unit surface area as the tube travels through the process. For example, a given tangent point on a 10-3/4” OD tube will contact a 20 foot long gravity skid about 7 times as it rolls down the skid. A given tangent point on a 2-3/8” OD tube will contact the same skid about 32 times, which presents far more opportunity for bar code damage.

Unfortunately, conventional paper or plastic bar code labels applied to the tube OD currently have little chance of readable survival in the tube mill environment. Mill abrasion, grease, gravity skids, tooling machinery, and straightener operations are just a few of the problem areas that deface barcodes and render them unreadable. But progress is being made every day on new and novel ways to apply bar codes on tube ODs. The solution may soon be found.

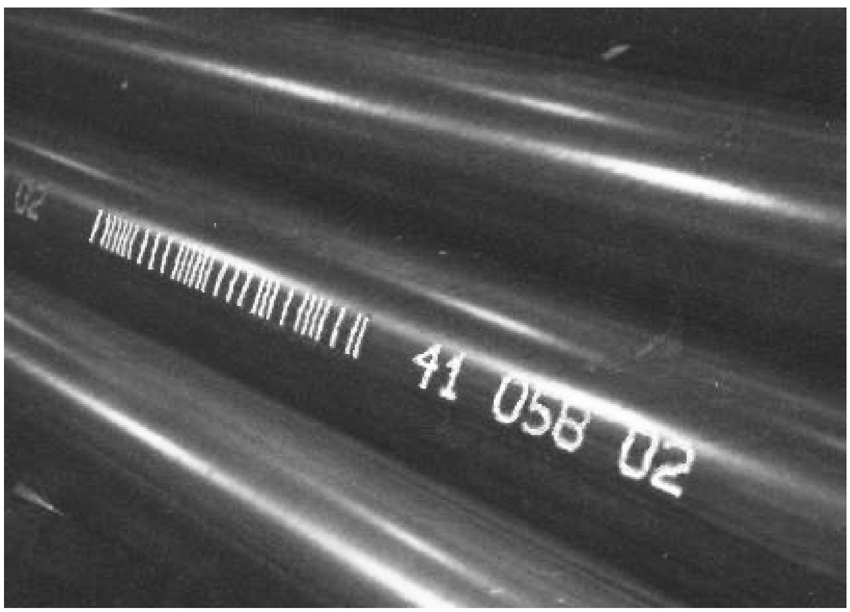

Figure 5 Binary dot matrix bar code on tube OD

Bar Codes on the Tube ID

In a second application, bar codes are applied to the inside diameter of large OD API Specification 5L tubes by a laser marker marking on a 200 mm (8 inch) square painted area. Text information and 4 redundant identical bar codes are marked on the tube ID. These bar codes are Code 128 symbology and are readable using standard handheld bar code readers. See Figure 6 below.

The bar code “enemy” in this case is rusty water settling in the bottom of the tube in outdoor storage, not manufacturing process damage.

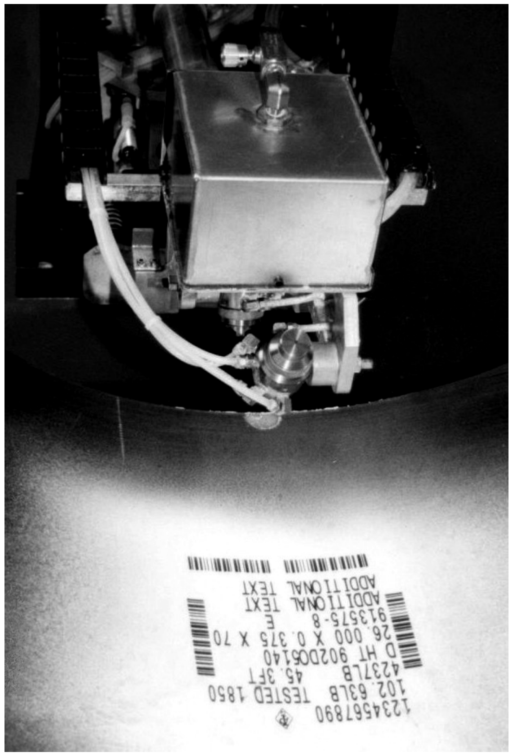

Figure 6 Laser-marked bar codes on tube ID

COST CONSIDERATIONS

In-line WMS systems are less expensive, primarily because of the considerably less hardware required for their operation. Equipment costs, not including installation, for in-line systems are typically in the range of approximately $120,000 to $180,000 USD depending on features implemented.

Cross transfer WMS systems typically range from approximately $250,000 to $450,000 USD, depending on type of transfer mechanism, tube diameter, tube length, tube weight and features implemented.

SUMMARY

WMS equipment automatically measures, and identifies tubes in the steel mill with minimal human intervention. High accuracy length and weigh measurement is performed and measured values are automatically saved for marking. Tolerance checking is performed to confirm the tube weight and length are within specified tolerances. Dot matrix stencil identification is performed. Optional color banding and stamping can be performed. Daily production reports and totalized tally reports are automatically printed. Progress in the marking of bar codes can facilitate automatic traceability. WMS equipment minimizes human error, eliminates manual tube measuring and identification bottlenecks, maximizes tube traceability, and ultimately improves the quality and throughput of the manufactured tubes.