Technology exists today to spray mark bar codes on the outside diameters of steel tubes and then read these codes using long distance high-speed video based bar code scanners at various downstream stations. This enables the ability to acquire and link downstream process results to each individual tube identity in a database in near real time, thus improving quality assurance and tube traceability.

Spray Marked Bar Codes on Tube OD for Traceability

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The ACIPCO[1] American Steel Pipe Division had a vision in early 1996 of being able to mark machine-readable marks on their large diameter (up to 24" OD) seam-welded steel tubes, in order to make it possible to identify the tubes at various downstream process stations. InfoSight Corporation was contacted to prepare a proposal for equipment to accomplish the vision.

InfoSight ultimately proposed large character (50mm high nominal) dot matrix marking equipment to mark both human-readable alphanumeric data and machine-readable bar codes on the tube. This equipment would be designed to interface with American Steel Pipe's database computer, both to receive information to be marked, and to upload tube identities at downstream process stations.

American Steel Pipe placed their first order for a marking system and a single downstream reader in January of 1998. These two pieces of equipment were collectively called "the pilot system", and their sole purpose was to prove (or disprove) the concept and feasibility of machine-readable OD marking in American Steel Pipe's Tube Mill. The marker was positioned to mark each tube at its "birth" – at the flying cutoff saw. The reader was positioned at the worst-case process position at the weigh scale – the final process before the tube leaves the mill and is placed into outdoor storage. If the mark could be marked at the beginning of the mill, survive the entire process and still be readable at the weighscale, then theoretically it could be read anywhere in the mill.

The pilot system indeed proved to be a success after an extensive testing period, and American Steel Pipe purchased four additional readers in mid-1999. These four additional readers were located at various key data acquisition locations throughout the mill.

[1] ACIPCO = American Cast Iron Pipe Company, located in Birmingham, Alabama, USA

The current marking and reading locations are identified as follows:

- I-DENT[2] marker at the Flying Cutoff Saw
- OptiCode[3] verifying single camera reader at the Flying Cutoff Saw (located right after the marker and used to verify the bar code after application)
- OptiCode dual camera reader at Preliminary Inspection
- OptiCode dual camera reader at Final Inspection
- OptiCode dual camera reader at Hydrotest
- OptiCode dual camera reader at the Weighscale

Figure 1 shows a graphic layout of the American Steel Pipe's Tube Mill and the various equipment locations. Figure 2 provides a photo of typical tube marking.

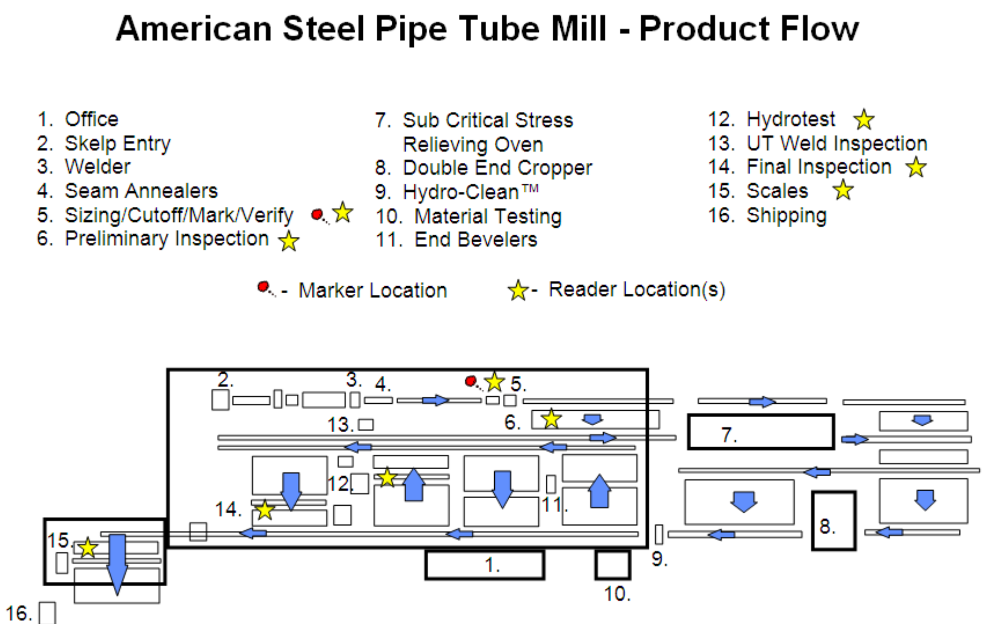

Figure 1

Figure 2

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[2] I-DENT® is a registered trademark of InfoSight Corporation, located in Chillicothe, Ohio USA

[3] OptiCode® is a registered trademark of InfoSight Corporation, located in Chillicothe, Ohio USA

Past History

Tube traceability and quality requires accurate, permanent identification immediately after tube "birth" at cutoff, before the tube manufacturing sequence becomes shuffled.

Historically, workers using chalk, paint sticks or punched stencils, have manually marked the tube ODs with human-readable characters. More recently, tubes have been automatically marked by automatic dot matrix ink spray equipment. Manual marking methods, using chalk or paint sticks, are prone to human error and are often illegible. Automated ink spray equipment can utilize accurate downloaded information but, if the marking equipment is not adequately maintained, the markings may be difficult to read.

When workers downstream read human-readable characters, data reading errors often occur. Transpositions, misreads, and other data logging errors are some of the common mistakes.

Automatic identification in the form of bar codes can significantly reduce errors if the tubes are identified with robust, high quality bar codes. Bar codes can easily be scanned during subsequent production operations using long distance video-based bar code scanners such as the OptiCode System.

In the case of American Steel Pipe, identification of tubes requires use of ink that can survive short duration temperatures in excess of 900°F (approximately 482°C) as the tube passes through American Steel Pipe's Sub-Critical Stress Relieving Furnace. The ink must also be able to survive outdoor storage without image or contrast degradation.

Equipment

The I-DENT marking system (see Figure 3) consists of the following:

- Electronics Enclosure in a NEMA12 enclosure with door mounted control panel
- 9 nozzle Printhead
- Ink Panel with pressure pot ink and solvent containers
- Maintenance Pendant, used for printhead cleanup
- Encoder, coupled to a mill roller to supply tube speed feedback
- Operator Terminal
- Interconnecting tubing and cables
- The inclined printhead array of nine (9) nozzles is used to spray 7x9 characters approximately 50mm high on a moving tube.

Figure 3

The OptiCode reading system (see Figure 4) consists of the following:

- Electronics Enclosure in a NEMA 12 enclosure with door mounted LCD video display
- Single camera (verifier only) or dual cameras mounted on common baseplate, with lens appropriate to required focal distance, mounted in industrial enclosures
- Diagnostic LCD video terminal, used for camera focusing and setup
- Interconnecting cables
- Bar code is scanned and decoded using video technology whereby the horizontal video frame lines pass thru all of the bar code "bars". The video signal is analyzed and instantly decoded to obtain the bar code value.

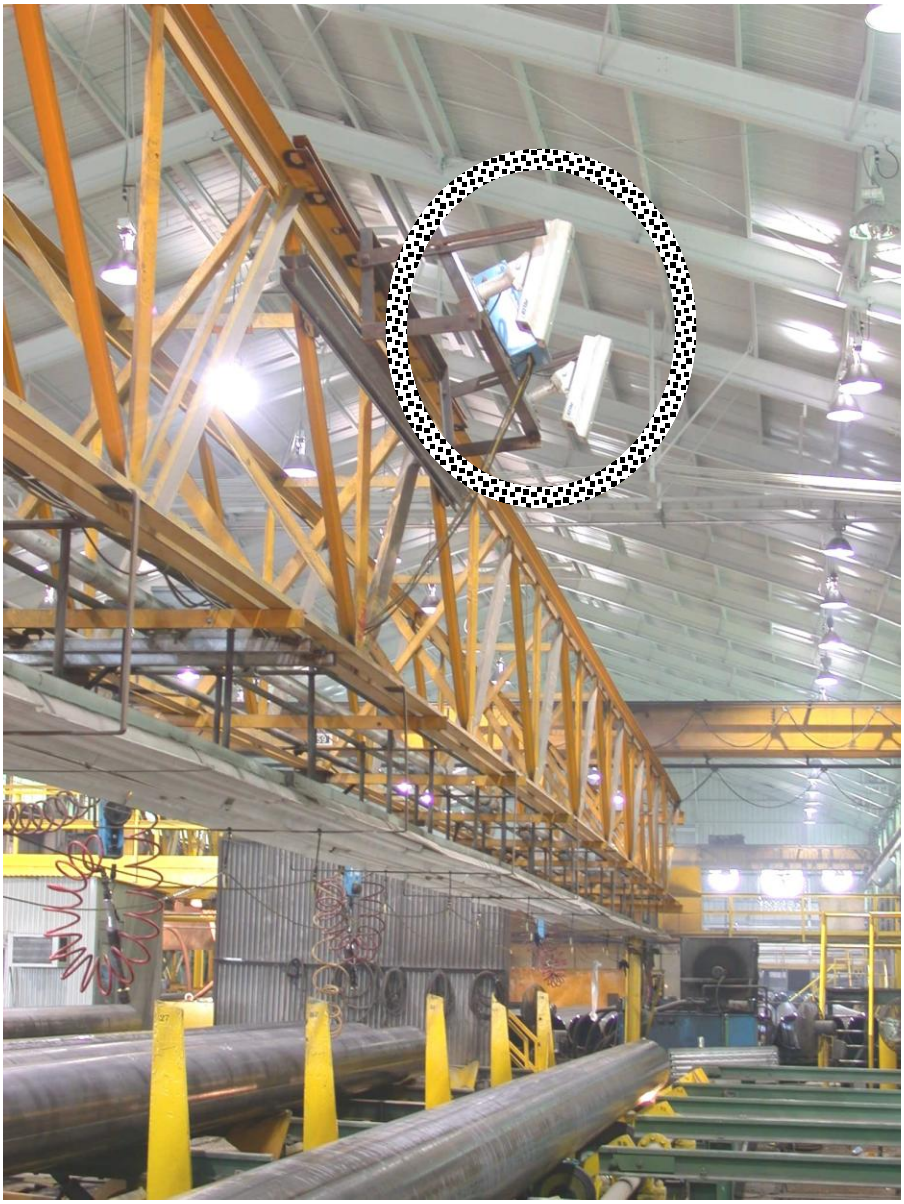

Figure 4

Data Composition

A graphical description of the tube marking and verifying process is shown in Figure 5.

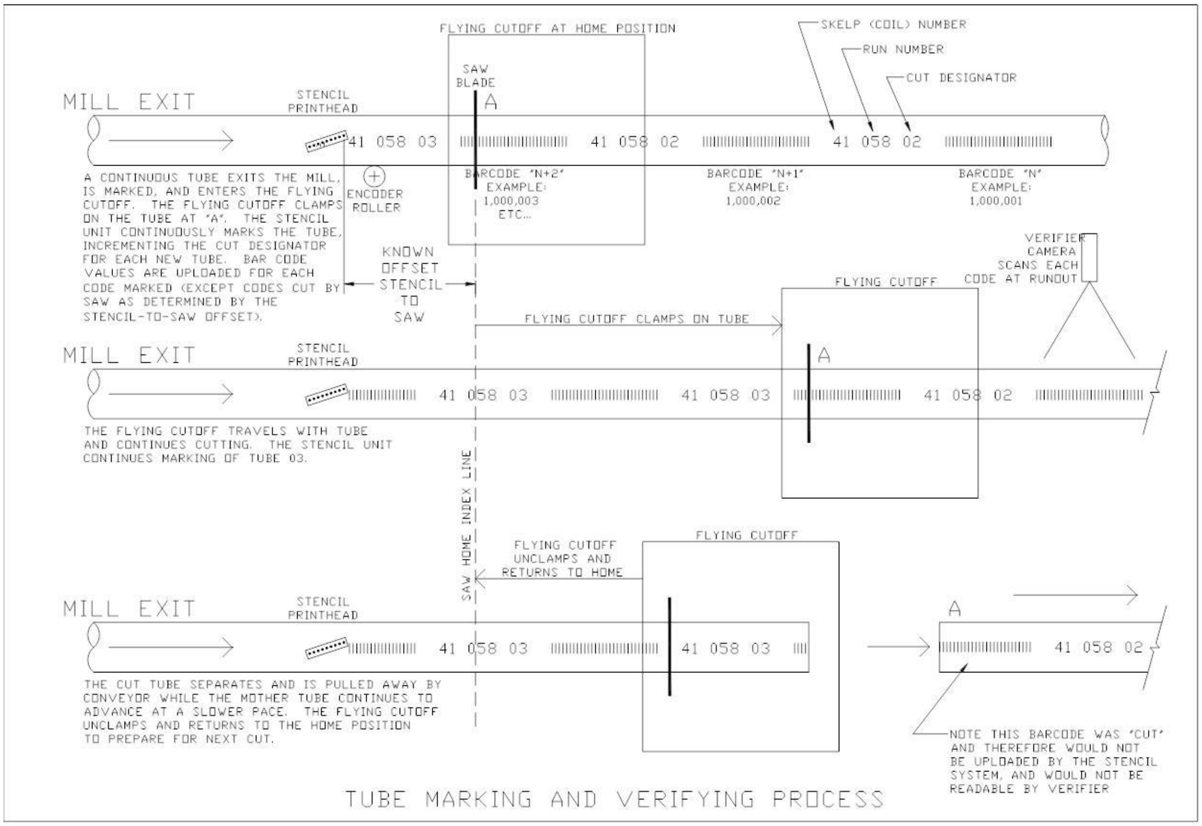

Figure 5

Both human-readable and machine-readable markings are marked on the tube as a set. A nine (9)-nozzle printhead is used to mark the data in a 9-dot high dot matrix array. The human readable mark is called the Skelp ID number, and the bar code is called the PIN (or piece identification number) bar code.

Skelp ID Number:

The human-readable portion of the set is called the "Skelp ID Number", and is marked on the tube in the format "SSSS RRR NN" where SSSS equals a four digit "Skelp" (coil) number, RRR equals a three digit "Run Number", and NN equals an incrementing Cut Designator "01", "02", "03", etc., for each tube cut from the current skelp (coil). See Figure 5.

The marking set is repeated down the entire length of the tube as it enters the flying cutoff. Each barcode increments by one (1) from code-to-code (*not* from tube-to-tube), thus one tube can have multiple different barcode PIN values on it. The logic behind this is (1) to maintain the ability to discriminate head end from tail end of a given tube, and (2) if a given tube is cut into two (or multiple) tubes later in the process, it is still possible to associate unique barcode identities with these cut tubes.

American Steel Pipe controls notify the marker when cutoff will occur via discrete signal, and for the next tube, the marking sets continue to be marked, with barcode, down the length of the tube. The bar codes continue to increment by "1" from code-to-code, and the incrementing Cut Designator for *all* marking sets on that tube also increments by "1". See Figure 5.

Upon completion of marking of each tube, the I-DENT system uploads the values of all barcodes marked on a given tube, and the database computer stores those values in a database as data record entry vectors for future bar code reading operations. The I-DENT system also intelligently determines if a bar code will fall in a position whereby it will be cut by the flying cutoff saw (by knowing the offset distance at the time of cut from the printhead to the saw blade at the home position). If a given bar code is "cut", the stencil system will not upload that code.

Immediately after the flying cutoff, the OptiCode single camera verifier scans and uploads a machine-read value for each barcode as the barcode moves laterally through the camera field-of-view on the conveyor. The database computer constantly compares the verify values with the just marked values. If the database computer detects a multiple code no-read duration, it issues an alarm to alert the marking operator to check the marking operation. Thus, there is a relatively immediate notification of a marking quality problem.

At the downstream reading stations, a pair of fixed mount cameras views each tube at a spin roll station. The camera's overlapping field of view geometry is designed to always capture at least one bar code in the total field of view. The tube is rotated in various spin roll stations, and the bar code is read as it scrolls through the camera field of view. See Figure 6.

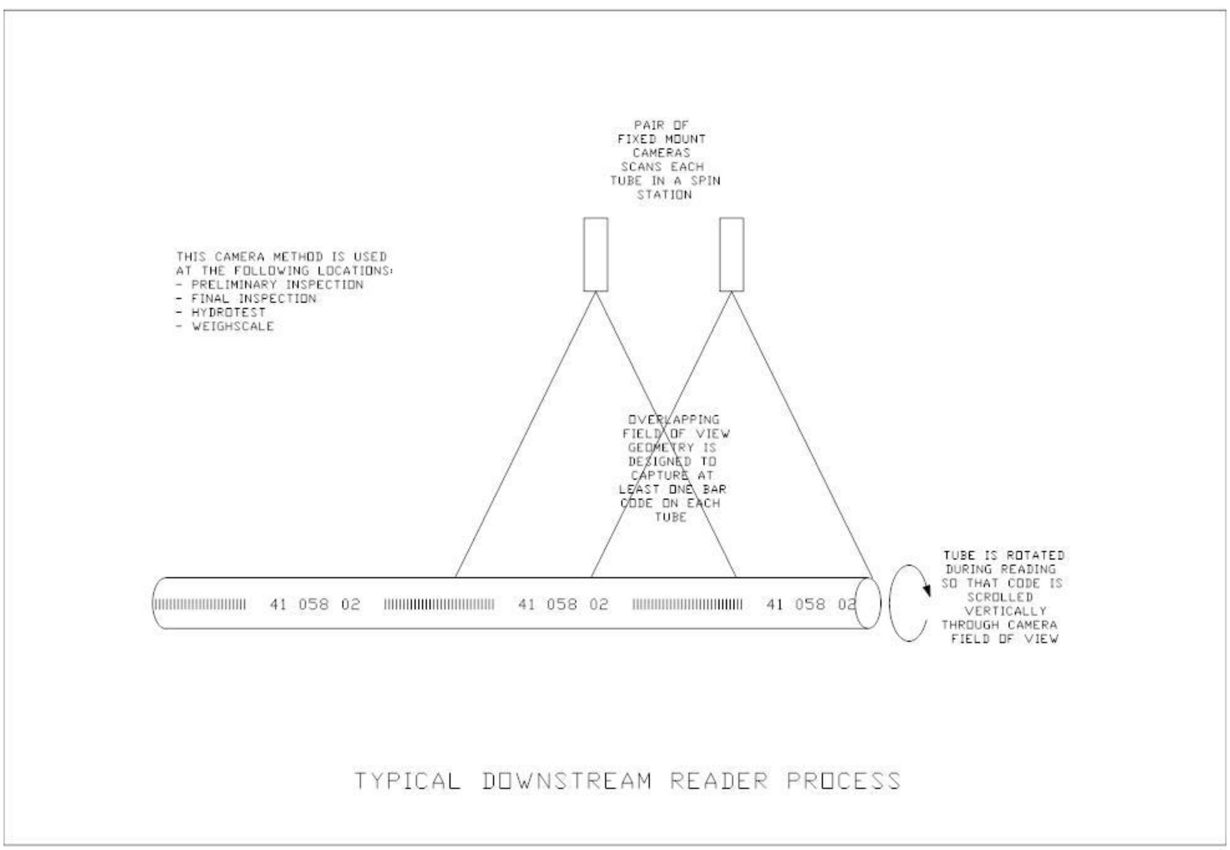

Figure 6

Database Computer and Record keeping

Figure 7 shows the marking and tracking computer system hardware arrangement.

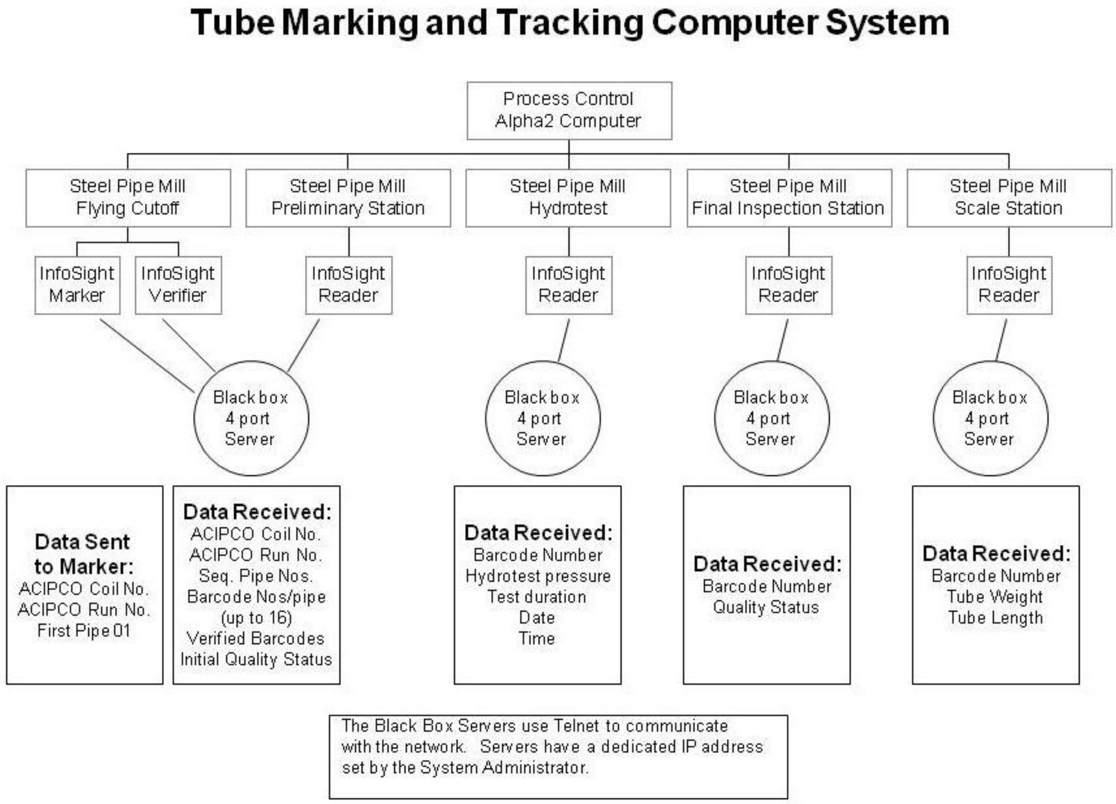

Figure 7

Data record fields collected by American Steel Pipe include the following:

- Bar code values marked on each tube
- Bar code values verified on each tube
- Preliminary Inspection results - initial quality status
- Hydrotest results - test pressure, test duration, date, time
- Final Inspection results - quality status (reject codes & footage where applicable)
- Scale results – tube weight and length
- American Steel Pipe barcode shipping tag applied – tag data includes: pipe lot number, pipe grade, hydrotest pressure, pipe length, pipe weight, etc…

With a minimal amount of paint system management, the successful tube identification read rate averages in the high 90's percentile range.

Bar codes and automatic tube tracking

Bar codes can provide the missing link that is necessary to facilitate automatic tracking in the tube mill. The bar code typically encodes a Piece Identification Number (or "PIN", also sometimes referred to as a "license plate number"), which is used to access a mill database containing a complete history of manufacture (or "pedigree") for that tube.

Bar codes can significantly reduce the number of occurrences of wrongly identified steel. As stated previously, human reading errors in the steel mill environment are common. Tests show that manual reading errors resulting from the combination of poor markings and fallible human workers in a mill environment are as high as one in 300. Large robust bar codes scanned by relatively inexpensive hand-held bar code scanning equipment can reduce the misread error rate to less than 1 in every 250,000 read attempts. Long distance bar code scanning equipment can be used to scan bar codes in environments less desirable for humans.

Good bar code practices must also be observed in order for identification methods to succeed. The bar code should be robust enough to survive the mill environment while still maintaining good scanability. The bar code size is a tradeoff between long-distance scanability and code size (and therefore code cost).

The following bar code "ground rules" are recommended for a robust bar code identification system:

- Keep the PIN short, ideally no more than 2 million permutations. Bar code density increases, and associated long-range scanability degrades, as more permutations are added.
- Use the PIN as a pure tracking number; don't try to encode the "entire tube history" into the bar code. The PIN should simply be used as the "key" to vector to the database record for the tube.
- The total number of available PIN numbers (and the corresponding number of database records) is calculated according to time duration needed to track a given product population. The PIN number and database record for a given tube is archived after the tube has left the population. The PIN number and database record for the (retired) tube can then be reset and reused to identify a new tube entering the population. The PIN used at American Steel Pipe contains approximately 2 million permutations and will serve the pipe mill for approximately one year duration without duplication.
- Maintain a good "clear zone" (clear area with no marking) at both ends of the barcode.
- Maintain good bar spacing control (function of marking system).

Factors for success

There are many factors that contribute to the success (or failure) of machine-readable tube OD marking:

- The location of the mark must be "viewable" by the reading system at all locations. In the case of American Steel Pipe, the code is either viewed (a) immediately after marking (as it leaves the flying cutoff) or (b) in spin roll stations used at downstream locations to rotate the tube and thus the bar code through the camera field of view.
- The process must take into account any worst-case end-crop operations, which may cut off or completely remove the barcode identification at the end of the tube.
- Camera fields-of-view must be designed so they can capture "any-case" bar code positioning. If bar code position by tube end justification cannot be guaranteed, consider designing fields-of-view to capture repeating codes possibly anywhere within the full length of the tube, as American Steel Pipe has done.
- The bar code must not be damaged by the process, for example, by straightening. If a damaging process is unavoidable, then it may be necessary to read the tube identification prior to the damaging process, followed immediately by tube remarking after the process. Simple testing can be performed to quickly reveal the extent of damage to the bar code.
- Any tube mill wanting to implement bar code tracking should first conduct a proof-of-concept trial using a pilot system, including a reading test after the entire process, prior to implementing a complete plantwide system.
- In general, machine readable tube OD marking and reading has a higher probability of success on large diameter tubes vs. small diameter tubes, simply because larger

marks are possible and the percentage of tube surface area damaged by handling (conveyor vee roll contact, table skid rubbing, for examples) is much smaller on a per-tube basis.

Cost Justification

If a tube is not identified promptly after cutoff, the tube's traceability back to the parent coil is in doubt downstream. Any resulting mixed product resulting from the incorrect identity produces real costs that sometimes do not appear on a cost justification spreadsheet for identification methods and equipment.

Examples of costs and liabilities related to mixed steel include:

- Customer returns or back charges
- Lost customers
- Legal liability due to mixed steel
- Unnecessary work-hours spent unraveling mix-ups
- Shipping delay costs
- Downgraded (or scrapped) steel
- "Lost" tubes in storage

Product traceability has become a very important issue to Pipeline Operators and Manufacturers alike. A robust traceability system provides Pipeline Operators an increased confidence in the pipe installation and maintenance. Many tube manufacturing facilities have historic "mix-up costs" due to shipping errors. These errors sometimes lead to field failures, which can become costly. Any justification for tube identification budgets should take into account the added value of improved steel identification, traceability, and security.

Summary

The technology exists today to automatically mark a durable OD mark on steel tubes at tube cutoff. The mark can clearly display both human-readable information, and a PIN bar code. The PIN bar code is used to identify each tube, and to access and add information to a database that will ultimately contain the tube's entire manufacturing history, or pedigree. The mark can usually be applied to hot or cold steel and can survive annealing.

A pilot system can be implemented to prove the feasibility of the marking and reading process through the entire mill, prior to total plant implementation.

The reduction in occurrences of incorrectly identified steel results in real cost savings and increased customer satisfaction that can easily justify implementation of the technology.