Applying Eddy Current Inspection

By Brian Roberts

Brian Roberts is Vice President of Advanced Kiffer Systems, Inc., Cleveland, Ohio. This paper was originally presented at the Society of Manufacturing Engineers, 17 May, 1999.

Eddy current testing has become the most widely applied nondestructive inspection method for the tube and pipe industry. Equipment is simple to install and operate, and provides a much needed monitoring facility for the weld mill at moderate cost.

Eddy current testing can be applied to all metals, both ferrous and non-ferrous at several stages of the manufacturing process. The purpose is, of course, to find and separate defective material, but also to provide mill operators with an early warning of subtle changes in the process which can often be corrected before scrap develops.

We estimate that more than 50% of tube and pipe mills in North America are now equipped with in-line test facilities and the majority are used principally for production control purposes.

Fundamental principles

Eddy currents are alternating electrical currents, usually of high frequency, which can be induced to flow in any metallic section, their flow pattern being disturbed by the presence of cracks or other discontinuities. The flow pattern of the eddy currents is either circumferential, using encircling or concentric coil configurations, or a tangential or circular pattern when using a surface or pancake coil configuration. (Fig. 1)

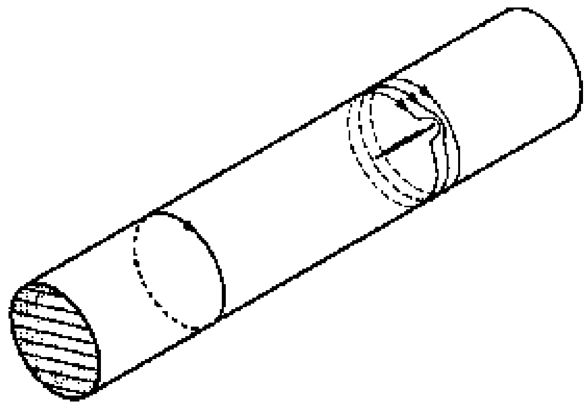

Fig. 1. Eddy current flow patterns

The eddy currents have their own associated magnetic field pattern, which is detectable by electromagnetic means. The presence of a crack or detriment in the material affects the flow pattern of the eddy current, which in turn affects its associated magnetic field, and the change is detected by a suitable search coil arrangement. The search coils are usually wound in the form of a differential transformer, with the primary or excitation winding being fed from an oscillator. Two secondary windings observe the eddy current effects at displaced sections of the material under test, and automatically compare the cross-sections for any differences which may occur. (Fig. 2)

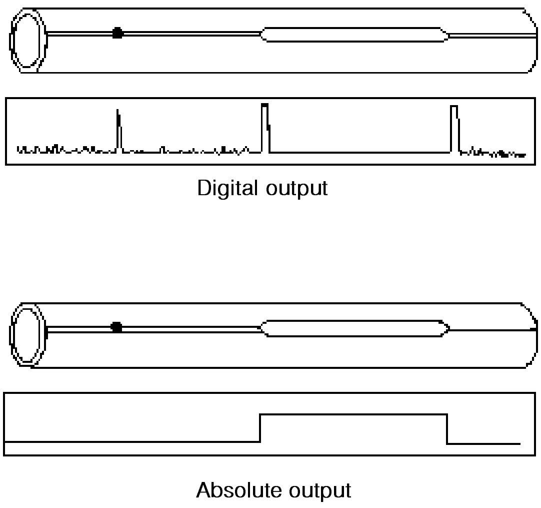

Fig. 2. Differential and absolute outputs

The obvious limitation of this form of inspection is that no difference in cross-section occurs if a defect is continuous for the whole length of the material. In practice, most defects are fairly intermittent in nature, but where it is necessary to detect "absolute" type defects, then it is possible to augment the differential winding (or windings) with an extra facility known as an absolute channel. The use of an absolute channel in tube mills is primarily to detect open seams.

When testing ferro-magnetic materials, magnetic polarizing assemblies are employed, principally to reduce permeability to a low and constant factor. In these circumstances, eddy current signals may sometimes be influenced by magnetic flux patterns that develop around discontinuities. Most eddy current test units analyze signals for amplitude, phase relationship and frequency patterns and are able to automatically discern flaw signals from the general

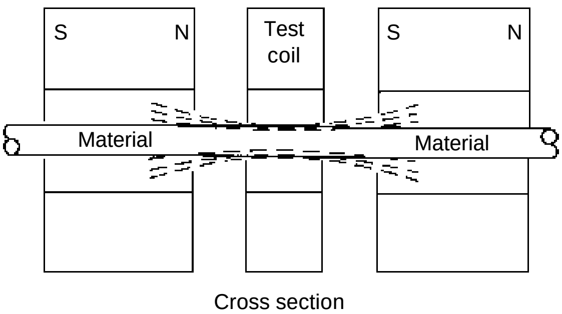

Fig. 3. Magnetic saturation

noise created by vibration and dimensional and metallurgical variations. Such filtering techniques have enabled higher sensitivities to be achieved, but care has to be taken to ensure that the same signal processing techniques are not abused in the interest of detecting standards, while ignoring defects. (Fig. 3)

Higher usable sensitivity offers the option to detect more of the flaws than was previously possible, and to enjoy large clearance factors between the search coil and material with obvious benefits in mechanical reliability. In the past, this clearance factor between search coil and material was one of the principal limitations for in-line inspection. Typical clearances were only on the order of 0.020 in. and the mechanical reliability of the system in a mill environment was very poor indeed. With modem coil constructions and electronic techniques however, clearances of up to ¼ in. can now be obtained with obvious benefits in total reliability of the system.

Development of automatic solid state balance control has virtually eliminated the need for operator supervision, other than for effecting size changes, and long term stability can now be measured in years rather than in half-hour periods.

Depth of penetration

It is a popular misconception that eddy current testing is only capable of detecting surface defects. This is true of rotating probe systems, but when testing tubing with encircling or saddle type coils, LID defects have been detected on ½ in. (12.7 mm) wall carbon steel and stainless steel material. Depth of penetration is defined as the point where the eddy current density has decreased to 37% of its surface value. On carbon steel tube which has been magnetically saturated, a typical penetration depth using a test frequency of 10 kHz is around 0.120 in. (3 mm). A more recent technique, however, is not to magnetically saturate the material, but simply to polarize it. This results in sensitivity to defects at a much greater depth produced by magnetic flux leakage effects on the eddy current flow pattern.

What can be detected?

Sensitivity is adjustable to suit individual customer requirements. The system is usually calibrated to meet approved standards such as American Society

for Testing and Materials (ASTM) or American Petroleum Institute (API), which relate to the detection of drilled holes or notches of prescribed dimensions.
To be detectable, natural defects must produce a disruption of the eddy current flow pattern which is equivalent to or greater than that produced by the calibration standard. They must also, of course, occur within the field of inspection. They probably will not be visible at the surface.

Typical flaws which show-up, include:
1. Pin-holes
2. Cross cracks
3. Seam cracks
4. Porosity
5. Lack of fusion
6. Loss of scarf
7. Scarfing chatter
8. Impeder loss or inefficiency
9. Lamination
10. Butt welds
11. Hook cracks
12. Edge damage
13. Burred edges
14. Open seams

Ultimate sensitivity is limited by the tube quality itself. For example, higher sensitivity is generally possible on cold-rolled rather than hot-rolled material.

What cannot be detected?

Typical defects that may be missed by eddy current inspection:

1. Slight undercut or overcut of scarf
2. Absolute loss of penetration
3. Certain "pasty" welds
4. Defects occurring outside the field of inspection
5. Brittle welds
6. Signals not exceeding calibration levels
7. Defects which are created during subsequent processing

Categorization of defects

Some manufacturers only want to find defects which fail a flattening flare test, or pressure test. Eddy currents cannot be that definitive. Many serious defects may be detected by eddy currents which pass mechanical tests. Conversely, a perfectly good weld may pass the eddy current test but fail the flattening because of brittleness.

From a production control standpoint, there are just two categories of weld problems:

1. Those inherent in the skelp which cannot be corrected by the mill operator.
2. Those created by the manufacturing process itself.

When anomalies of the second category occur, the mill operator should respond with immediate corrective action so scrap is minimized. Unfortunately, the unit cannot be definitive. It merely draws the operator's attention to a change in condition which must be correctly interpreted.

Magnetic properties of test material

Our first consideration is whether the material to be tested is austenitic (non-magnetic) or magnetic in nature. If the latter, we have to suppress the magnetic properties in order to get eddy current penetration into the material and to eliminate magnetic variables which are created from stresses introduced by material handling processes such as forming and sizing. These variables create erroneous signals which reduce sensitivity to real defects.

Suppression of magnetic properties is achieved by saturating or polarizing the material with a strong magnetic field at the point of test. On thin walled material or when the test zone is still at an elevated temperature, sufficient magnetic field may be generated by permanent magnets for testing the weld seam only. For other conditions, the magnetic field needs to be generated by electromagnetic techniques.

Magnetic materials include all carbon steels and 400 series stainless steels. Certain grades of 300 series stainless steel and some 800 series nickel alloys (which are normally considered "nonmagnetic") may display magnetic characteristics after welding, but this is seldom detrimental to the test unless the customer wishes to work to an extremely high order of sensitivity. We usually recommend the use of "saturation" with these alloys for super-critical applications, more as a precaution than a necessity.
Precipitation of "delta-ferrites" on 304 and 316 grades

has also been observed in instances where the weld has not been fully annealed. Again, this can be overcome for the purpose of eddy current testing, by the application of permanent magnets to mask the ferritic influence.

Eddy current transducers

The second consideration is the practical methodology which we can apply in relation to available eddy current transducers. There are literally hundreds of types available, but eight group classifications are reviewed. (See Fig. 4.)

(1) Flat pancake coils
These are available in discrete sizes with sensing widths up to 10". Applied to the inspection of skelp at the entry to the forming section to detect and track butt welds to raise scarfing tools and cut-out operations. Also used for the inspection of squares and rectangles after shaping where the heat-affected zone is on the flat.

(2) Seam inspection probes
Located on the weld platform to test the weld seam only. Fitted with differential detection windings to provide a monitor of weld condition and absolute windings to detect (separately) open seam conditions for corrective action with seam annealing, bright annealing and in-line plating or coating operations. One size fits all.

(3) Segment probes
Cover a quadrant on round tubes to permit inspection of the heat-affected zone after cooling. Effective arc is around +/- 1 1/2" (+/- 40 mm) either side of top. Mainly installed at the entry to the sizing section.

(4) Half moon probes
Accommodate weld wander up to 90 degrees either side of TDC for diameters below 3 1/2" (90 mm). Need to be matched to tube sizes in 0.200" (5 mm) increments.

(5) Corner probes
To check shapes where the weld seam has to be formed in or close to the comer.

(6) Encircling coils
Full body testing usually applied after sizing. Coils and associated bushings need to be matched to individual tube diameters. Ideal for small diameter mills (refrigeration, heating element, cable sheathing, etc.). Sensitivity falls off as size increases. Tubing needs to be sized to conform with coil aperture. Splits (open seams) may cause damage. Major interference problems from loose I/D scarf. The only realistic

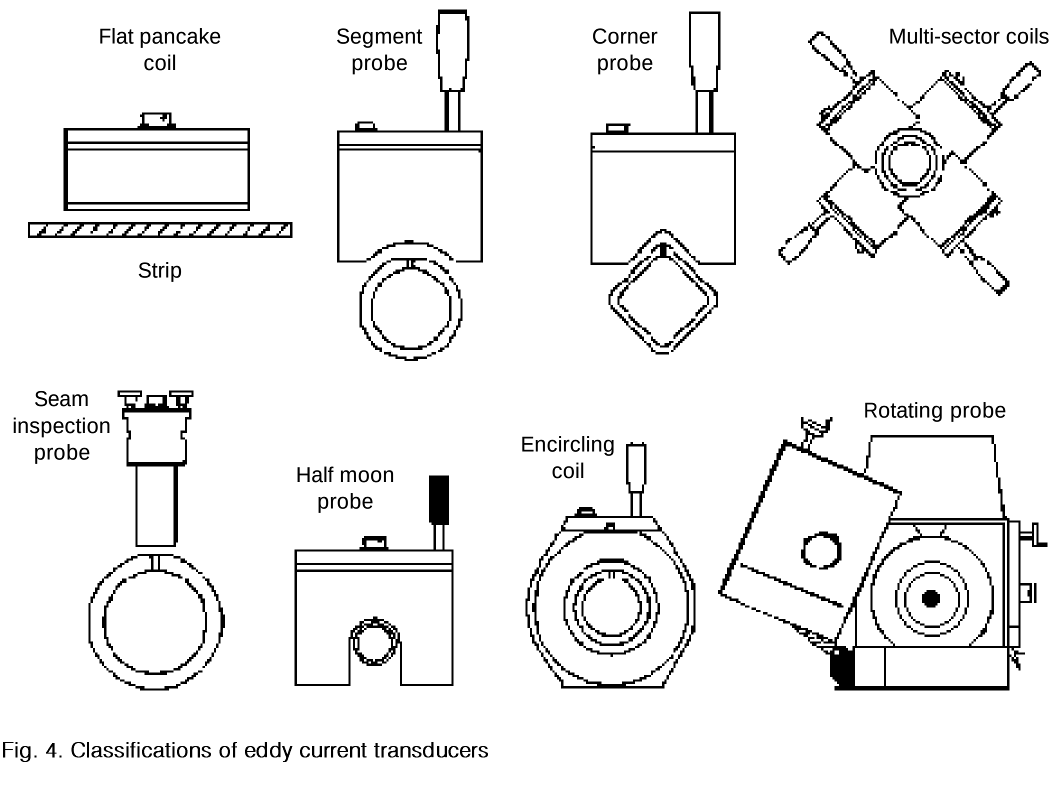

Fig. 4. Classifications of eddy current transducers

mounting location is between the penultimate and final sizing stands, but space is rarely available.

(7) Multi-sector coils
Full body testing achieved by a series of segment probes arranged in a radial pattern around the tube or pipe. Significant advantages over fixed encircling coils particularly for sizes 3" (80 mm) and above.

(8) Rotating probes
Heavy duty assemblies utilizing high speed rotating inspection probes to check for longitudinal surface cracks. Can only be applied after the weld seam has been fully annealed. Prior to annealing, the seam is detected just like a butt weld. Great test that the anneal has normalized the heat-affected zone.

Mill locations (Fig. 5)

From a production aspect, it is desirable that testing occurs as soon as possible so that the mill operator gets the earliest possible warning of a deteriorating weld condition.

From a quality aspect, it is better to carry out the test as late as possible since defects could be introduced by the quench and sizing operations and it is advantageous to exert force on the weld seam to open up potential weaknesses.

There are five possible installation sites in a typical tube mill:

1. Entry to the forming section, to detect butt welds, surface-breaking lamination and holes in the skelp.
2. Immediately following the scarfing or bead rolling operation while the weld is still very hot using air-cooled or water-cooled probes.
3. Within the quench tank itself using special waterproof head assemblies.
4. At the entry to the sizing section, after cooling. This is the most popular inspection position where the tube is cool, clean and the weld has not twisted too far. Weld twist up to 90 degrees either side of top can be accommodated with modem sector coils.
5. After sizing, but before the turkshead. Either full body testing or weld sector inspection. Full body testing may not be practical if the tube has been I/D scarfed and the fin cut still lies within the tube.

Testing after the turkshead is seldom practical because of vibration from the cut-off and the variable tube pass-line. This is where we install our automatic marker to accurately pin-point the position of flaws on the tube. Marking inks are generally used, in preference to paint. Accuracy is maintained by a distance encoder which tracks flaws from the inspection point where they are sensed, to the cut-off where they are marked and possibly cut-out or sorted.

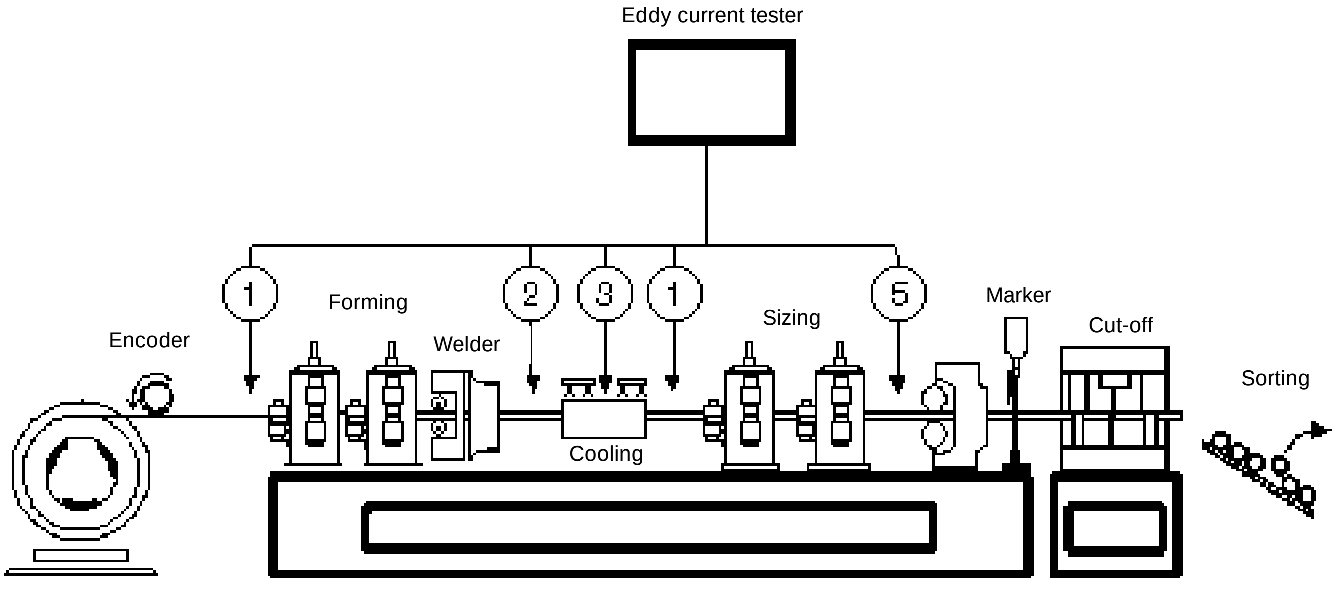

Fig. 5. Five possible installation sites in a typical tube mill

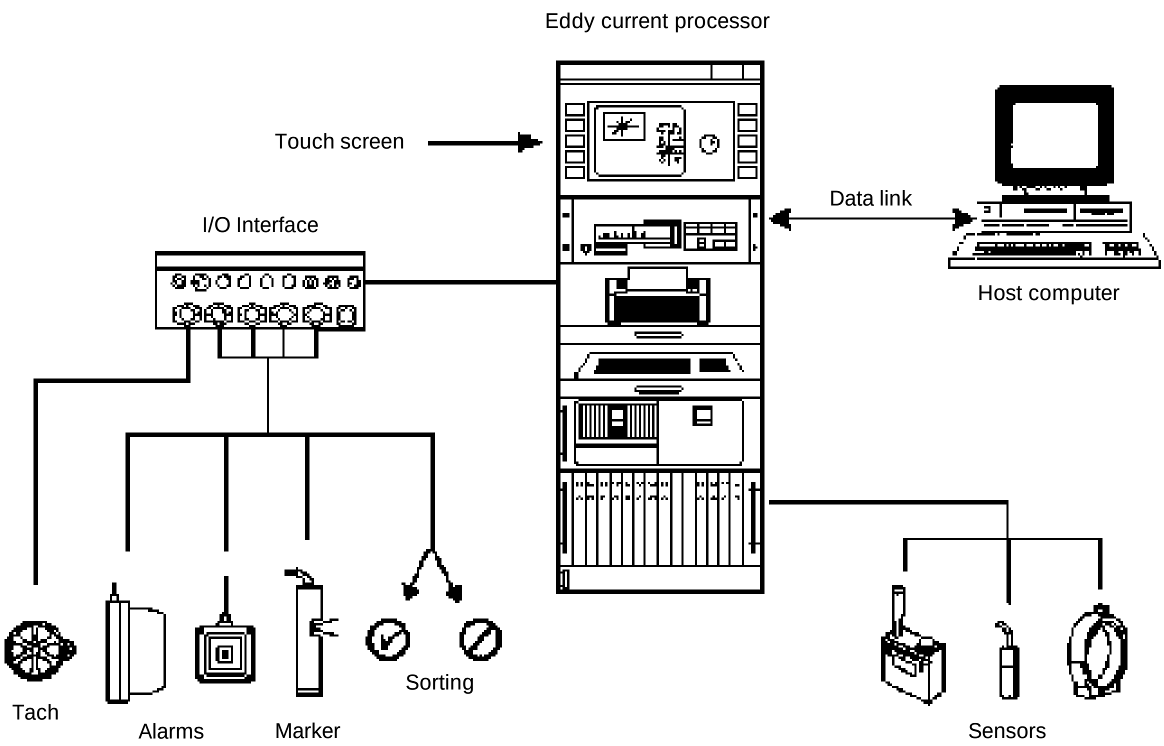

Fig. 6. Example of a complete eddy current inspection system

The tester itself

The advent of digital electronics and computerization has opened up opportunities of multi-channel eddy current testing capable of unprecedented accuracy and control.

In the example shown (Fig. 6), up to 8 channels may be accommodated in the same frame allowing for incoming strip, seam weld, and full body testing all on the same unit. Real time monitoring shows each channel simultaneously in a different color. Initial set-up procedures are entered via a touch screen (Fig. 7) and stored on file in the on-board computer so that when a size change is made, the operator only needs to enter the tube size to be tested. Otherwise, the set-up file may be accessed from the host network. Each coil or probe has an imbedded identity chip to communicate that it is the correct transducer for the job.

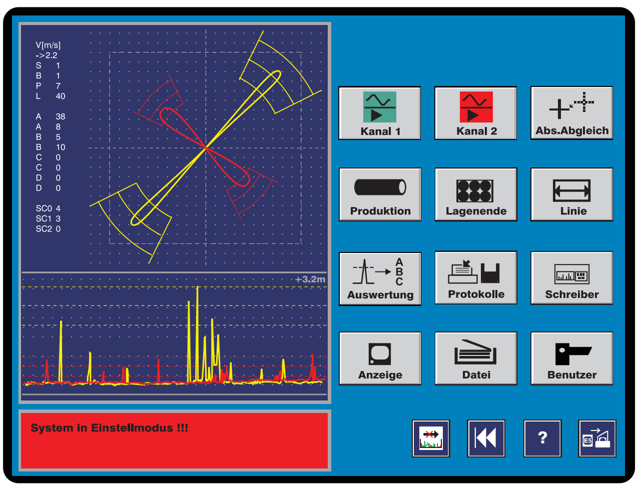

Fig. 7. Touchscreen for parameter input and signal display

Data archiving

Data is collected on batch numbers, transducer identity, test frequencies, amplifier gains, vector gates, trigger levels, line speeds and defect occurrences with subsequent marking and sorting actuations.
Typical histograms can be recorded related, e.g. to each coil (Fig. 8) or to individual cut length tubing or pipe (Fig. 9). Alternatively, customized reports can be generated using Windows-based software packages such as Excel.

Coil report

Time coil commenced
"B" level defect 120ft from start, 10ft scrapped
Prewarning to operator 850ft to 970ft along
"A" level flaw (minor) 1790–1800ft (marked but not scrapped)
"B" level defect 2540ft, 10ft scrap
"B" level defect 3460ft, 10ft scrap
"B" level defect 4380ft, 10ft scrap
Printout at end of coil
Time coil completed
Machine operator
Material code, customer I.D., etc.
Actual length tested
Amount scrapped
Amount with minor flaws
Yield for coil

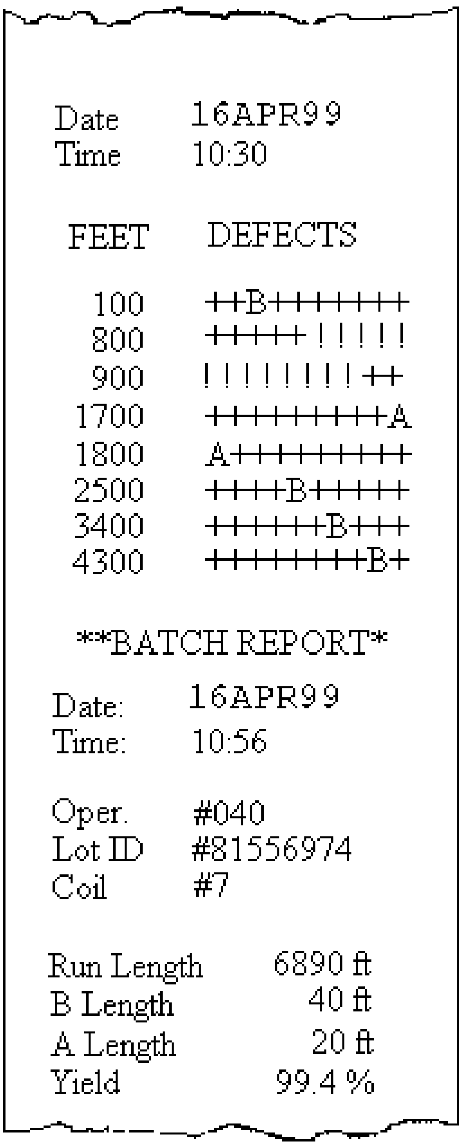

Fig. 8. Typical histogram providing testing information related to each coil

Cut length report

	Mill #:	2
Time coil commenced 1:05p.m. (24 hour clock)	Date:	16APR99
	Time:	13:05
	TUBE #	FLAWS
8th tube rejected for "B" level flaw 30% along length	008	+ + B + + + + + + +
	021	+ + + A A A + + + +
Mill stop/start	STOP	13:10
	START	13:21
	134	+ + B B B B B B B B
297th tube rejected for intermittant "A" level flaw	297	+ A + + A + + A + +
	298	A A B B A B B B B B
	426	A A A A A + + + + +
433rd tube rejected for isolated "A" level flaw	433	+ + + + + + + A + +
	BATCH REPORT	
	Date:	16APR99
Time batch finished	Time:	13:57
Assigned operator number	Oper.	+052
Material or customer code	Lot ID	#2024
	Batch	#1
Total number of tubes produced	Run:	500 TUBES
Number rejected for "A" level flaws	A Rejects:	4
Number rejected for "B" level flaws	B Rejects:	3
Yield for the batch	Yield:	98.6%
Accumulated mill downtime	Downtime:	11 MINS

Fig. 9. Typical histogram providing testing information related to individual cut length tubing or pipe