OPTIMIZATION IN APPLICATION OF NDT IN PIPE MILLS

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Abstract: Tubular products in pipe mills are produced by different methods in wide range of sizes and materials for various applications . From simple ERW steel tubes to high quality and expensive seamless tubes, depending on the application, different NDT techniques are used extensively. All these tests are implemented to fulfil the required specification or standard as well as for condition monitoring of the production lines. While on-line test has the advantage of real time inspection by less investment, off-line test is final inspection and more reliable. Selecting a suitable NDT method is possible by optimizing between the costs and reliability in parallel with requirements of the international standards. Today different standards like API, ASTM, ANSI/AWWA, DIN, BS, SEP are used extensively in pipe mills but all these standards give options to select test technique and test palce . In many pipe mills NDT is not used as they beleive it is an expensive test that reduces the production speed . While, by implementing proper NDT method in proper stage it is neither expensive nor reduces the production speed . In this paper the applicable NDT methods are evaluated according to the international standards for various tubes on the base of longterm experience in Iranian pipe mills .

Introduction : Metalic pipes and tubes are classified in different cataegories depending on the material, size, production technique and applications. Seamless tubes are made directly from the ingot or bar. All other types are produced by rolling and welding the metal sheets or strips . Depending on the welding technology different group of pipes like ERW (Electric Resistance Welding), SAW (Submerged Arc Welding), GTAW (gas Tungsten Arc Welding) and other types can be identified . All these tubular products are considered as semi-finished products that are used in wide range for various applications like water piope, oil&gas transmission, boiler and heat exchanger tubes, tubes for construction works or for vheicle iindutries, chemical, petrochemical and power plants . All pipes are produced according to the international or national standards. Worlwide well-known standards have developed different sections for such products . According to the most of these specifications like API 5L, ASTM A53 DIN 2440, IPS , BS 1387, SEP 1917 and 1925 NDT must be imcorporated on production line for 100% inspection of the products . Furthermore, NDT is a reliable technique for process control and condition monitoring of the production line . By this control the real time supervision of production process mainly welding quality is carried out continuously and the rate of scrap is reduced considerably . According to the standards different NDT methods can be applied on production line for automatic testing of tubes : RadiographY&Radioscopy (RT), Ultrasonic Testing (UT), Electromagnetic Testing (Eddy Current and Leakage Flux Testing , ET) , Magnetic Particle Testing (MT), and Penetrant Testing (PT). Each method has its own advantages and also disadvantages in comparison with the other methods considering the application and the requirements. Some methods can be executed as on-line or off-line while some others can be implemented only as off-line inspection .

On-line testing has many advantages while off-line testing has some exclusive merits that makes it the only alternative in some cases . In the following after evaluating on-line and off-line testing , all applicable NDT methods in pipe mills will be dicussed and compared . Optimization between the requirements of the standards as well as the customers' satisfaction from one side and the costs from the other side will be discussed on the base of actual experiemtal evaluation on about 50 Iranian pipe mills .

Discussion : *1- On-Line / Off-line Testing :* In tube mills , tubes are produced either piece by piece or as a continuous product that is cut to pieces later on . Seamless pipes and some large diameter pipes are made piece by piece and testing is also should be done on each piece separately that is considered as off-line testing . But in most tube mills , the tubes are made by rolling or bending and welding the strip of plate on continuous roll mill . Then it is cut in pieces by desired length . On-line testing can be done before cutting . In some cases a piece of seamless or welded pipe is reduced in size by drawing and then cutting in small pieces . Here also on-line testing can be executed on drawing line before cutting. . On-line testing has many advantages as :

- Test is as fast as production speed .
- The pipes are tested on the same rollforming line and any separate handling mechanism is not needed .
- Test is a real-time process control of the production line . This will prevent producing any scrap .

The only advantage of the off-line testing is the possibility of testing at the final stage of production process . Therefore, where further process like heat treating, cold expansion , sizing or hyrostatic testing is done on pipes after cut-off and there is a danger of creating new defects or extending any small discontinuities , usually standards require off-line testing at the end of production process . According to API 5L paragraph 9.7.2 : " The location of the test equipment in the manufacturer's facility shall be at the discretion of the manufacturer, except that final inspection of weld seams of cold expanded pipe shall be performed after cold expansion . " So, according to this

standard if pipes doesn't go for cold expansion , on-line test will be acceptable . In some cases supplementary test is required . As Appendix F paragraph SR17.1 of API 5L , "Supplementary Nondestructive Inspection" : "The weld in ERW pipe shall be inspected full length for surface and subsurface defects by either ultrasonic or electromagnetic methods....The location of the test equipment in the mill shall be at the discretion of the manufacturer . However, the nondestructive inspection shall take place after all heat treating, hydrostatic testing, expansion and rotary straightening operation, if performed, but may take place before cropping , beveling and sizing of pipe. "
According to ASTM A53 and SEP 1925 , hydrostatic test can be replaced by NDT . In such cases if other mentioned post processes are not performed after cut-off , on-line NDT will be sufficient .
2- Pipe Defects :Pipe defects are generally classified as material defects and process defects . Material defects for seamless pipes are usual casting or forging discontinuities that should be tested in steel plants . Since the raw material is completely deformed in pipe mill the nature and dimensions of the inherent defects are changed during pipe fabrication . Therefore standards for seamless pipes require NDT only on finished pipes . But welded pipes are required to be tested for both material inherent discontinuities as well as the defects that are created during the following pipe fabrication processes like rolling, welding, sizing, heat treating, expansion , hydrostatic testing etc. ...
The material defects on welded pipes are the defects that are found usually on rolled plates like Lamination ,surface cracks, laps and dents . Such defects can be tested on sheets or strips before rolling or bending but since some hidden defects or small discontinuities are revealed or extended during further fabrication processes due to the heat or machanical forces, some standards require material testing at final stage of the production line . The major discontiuity of this type is inside lamination that is well detected by Ultrasonic Testing .
The defects in seamless pipes are classified as surface defects like cracks , Laps , dents on outside or inside surface of the pipe as well as the internal defects like prosity, lamination and voids .The other major defect in seamless pipes that should be checkd by NDT methods is thickness variation .
The process defects on welded pipes are usual automatic welding defects of different types depending on the weld design and welding technique. The typical weld defects of ERW pipes are : Lack of weld, Longitudinal cracks, Lack of fusion or weak weld, dents, excess bead, shallow or deep holes, The weld defects for SAW piopes are mainly : Longitudinal and transverse cracks, Lack of penetration, Lack of fusion, prosity, wormholes and inclusions .
Dimansional control like checking the diameter, thickness, ovality, length, straightness as well as material test for strength, hardness, composition ... can be a part of NDT purposes in pipe mills according to the requirements of applicable codes, standards or specification .
3- NDT Methods : Among the various NDT methods , the following techniques are applied in wide range in pipe mills :
3-1 : Radiography & Radioscopy (RT): Both technoques apply X-Ray to inspect the internal defects mainly on welds of the pipes . In Radiography , image of the weld section is produced on film while Radiography is the real-time screening of the weld on the monitor . Both techniques are applied mainly on welded large diameters usually over 20 inches pipes . The major advantage of RT is high reliabilty of the test technique as it gives a real picture that can be documented . But RT has some disadvantegs that creates limitations on application of it in pipe mills :
- X-Ray is hazardous to human body and very careful protection and strict rules must be observed .
- It cannot detect fine defects specially surface defects as well as plannar defects like lamination .
- It is relatively expensive and needs qualified and skilled operator and interpreter .

Some standards like API 5L accept 100% Radioscopic testing as a sufficient inspection to detect internal defects but some others like IPS don't accept it and require combination of Film Radiography with other methods like Ultrasonic or Electromagnetic testing .
In such cases always 100% UT or ET is required and additionally both pipe ends and defective areas that have been found by other methods as well as repaired welds must be tested again by Film Radiography . This is a common procedure in pipe mills who produce large size so called API pipes by SAW method for oil & gas transmission . RT is the idael method to detect most of the weld defects like prosity, lack of penetration, lack of fusion, slag or tugsten inclusion, cracks, undercut and excess penetration .
This technique is also used for thickness measuring on hot material that is applied in pipe mills who produce seamless pipes and the thickness must be controlled in several stages when the material is still red .
3-2- Ultrasonic Testing : By this method ultrasonic waves with frequency of 4 or 5 MHZ are used to detect the defects of weld or pipe body . It can be used either as on-line or off-line to test seamless or welded pipes . UT can detect nearly all important defects of the weld and pipe body . Besides of the defects taht were mentioned above ,

the lamination located inside of the pipe material can be revealed by normal ultrasonic waves that is considered as an exclisive technique to find this type of dicontinuities . As the requirement of some standards , the lamination of the pipe material should be checked by 12.5% to 100% of material either before or after rolling . Some specifications require lamination test on both sides of the weld after welding . Ultrasonic Testing can be used as on-line on ERW rollmil to check inside deburring after scarfing of the inside weld bead . UT can also be used for thickness measuring of the pipes specially on seamless pipe mills .Weld inspection is usually carried by angle probes in different angles depending on the thickness in X or K arrangements to detect longitudinal and transverse cracks as well as the volumetric defects . Besides of the other advantages , ultrasonic testing is completely safe and doesn't need any protection . Despite of all merits and extensive capabilities this method has also some disadvantages :

- Coupling medium like water is required .
- Both pipe ends cannot be tested that requires RT or manual UT .
- Skilled operator and interpreter as well as carefull calibration and maintenance is needed .
- It is rather expensive technique .

Full body inspection can be executed by array of probes or by rotating either the pipe or probe assembly . Also new developed phase array transducers are also suitable method for full body inspection without any rotation.

3-3- Eddy Current Testing : By this method an eddy current is induced inside of the pipe body by a test coil . Any disturbance of the eddy currents due to the any discontinuity of the material is reflected to the test equipment through the test coil . Depending on the material properties and exciting frequency , the penetration depth of the eddy current inside the pipe thickness differs . Two important properties of the pipe material that influence on penetration depth are Electrical Eonductivity and Relative Permeability . The penetration depth is decreasing by increasing Frequency, Electrical Conductivity and Relative Permeability . The highest penetration is achieved in austentic steel which has the lowest Relative Permability of 1 like non-ferrous metals and the lowest Electerical Conductivity like steel . Non-ferrous metals like copper and aluminum have low penetration depth due to possesing very high conductivity despite of the lowest permeability . But steel is different , as it has the moderate conductivity but the highest permeability much greater than 1 . Therefore, for steel besides of decreasing the frequency there is also the possibility to decrease relative permeability by magnetic saturation (see table 1) . So far by the available techniques , testing of steel pipes by eddy current method was successful upto thickness of maximum 15 mm .

Eddy Current Testing has many advantages in pipe mills :

- It is simple, non-contact , fast , safe and without any need for consuming material .
- It is much less expensive than other methods . Its cost is almost 1/5 of Ultrasonic Testing .
- Less skill and experience is required to operate the test system and interprete the test results .
- It is applicable to all metals . Specially on austenitic steel it has the highest penetration while Ultrasonic testing of such material is the most difficult and unreliable test .

Despite of all these advantages , the limited penetration of eddy currents makes this method applicable only for small size pipes .

Thus, this technique has found very extensive application in pipe mills who produce pipes below 8 inches . For meduim size pipes 8 to 14 inches it is used only to test the weld seam . Eddy current testing can be executed by a single probe , flat probe or coil, segment coil, or encircling coil for full body inspection of pipes . Rotating heads containing several sensitive probes or recently phase arrray probes are used to detect very fine defects on full body of the pipes .

3-4- Leakage Flux Testing : By this method the magnetized ferrous pipe is tested for magnetic leakage due to any discontinuity by a sensitive magnetic probes. Due to the necessity for rotating the probes around the pipes as well as high cost , this technique is used only on seamless high quality alloy steel boiler tubes . The advantages of this technique are as follows :

- It can detect very fine longitudinal or transverse defects .
- Almost all types of defects on outside or inside surfaces as well as internal defects of the pipe can be distinguished separately .
- It is fast, clean , safe and without any need for consuming material .

But there also some disadvantages :

- It is the most expensive NDT method for tube testing .
- It is limited to test only magnetic material.

- It requires more skill , experience and very carefull maitenance.
- To detect longitudinal and transverse defects 2 different systems are needed .
- It can be used only as off-line that makes is too expensive .

3-5- Magnetic Particle Test (MT): By this method the ferrous pipes are covered by magnetic particles during magnetizing the pipe body . Then the intended areas are inspected by operator visually . This method has several major limitations :
- It is applicable only on magnetic materials .
- It can detect only surface or sub-surface defects mainly cracks .
- It is a visual inspection and cannot be automated or automation is very difficult .
- It needs consuming material .

Due to these restrictions, the application of MT in pipe mills is only to test surface defects on areas that cannot be tested automatically by the other techniques . As usual it is used to test the welds on both pipe ends or repaired welds . The other common application of MT in pipe mills is lamination test of both ends of the pipes after bevelling .
Some advantage of this method is : Safety, fast , unexpensive, visible real test results , no need for high skilled operator and interpreter .

3-6- Penetrant Testing (PT) : In this technique, the test area is covered by liquid penetrant that is usually in red color after careful cleaning . After passing proper dwell time that will allow penetrant to enter inside of the discontinuities, the excess penetrant is removed from the surface . Then the test area is covered by white developer which absorbs the trapped penetrant from the discontinuity and reveals it on white background . The application , advantages and disadvantages of this technique in pipe mills is almost similar to MT except two important advantage in favour of PT that is :
- Possibility to use it on any non-porous material.
- No need for any equipment and electricity.

In comparison with MT the major disadvantage of PT is its longer test time that limits its application in pipe mills . The other point is taht PT can be used to find only the defects that are opened on surface while MT can detect some sub- surface defects upto some extent by DC magnetization as well.

Results: Comparison of test methods considering their capabilities, advantages and disadvantages should be done in relation with the production process, application of products and applicable codes, standards or required specification . A general comparison is shown in Table 1.

The practical evaluation has been done on about 50 pipe mills in Iran based on 20 years closed relationship and cooperation with these plants as a NDT specialst . In almost 30 plants NDT is used considerably but the other 20 plants who mainly produce water pipes or construction tubes don't apply NDT extensively. Water pipes are mainly produced as ANSI/AWWA standard that doesn't require NDT as a mandatory routine test . According to this standard only : "Special sections shall be tested by nondestructive testing methods, which may be dye penetrant, magnetic particle, ultrasonic, or radiography, as specified by the purchaser. In the absence of such purchaser specifications, the nondestructive testing method shall be chosen by the manufacturer." In such plants hydrostatic test is the major requirement that should be appiled on 100% of the products . Of course, most of the 30 plants who have NDT systems produce water pipes as well but intersting is that they use on-line NDT also on water pipes. In most cases they replace hydrostatic test by 100% NDT of the full body as accepted by some well-known standards . Additionally, such on-line testing is a type of procees control and gives them more confidence on the quality of their products . Among the 30 evaluated plants 22 of them produce small size pipes mailny below 6 inches in diameter and thickness of less than 5 mm. For such products Eddy Current testing is ideal method to fullfil the requirements of almost all International and national standards like API, ASTM, DIN, ISO or IPS .
Applying on-line full body eddy current testing and deleting hydrostatic test is the optimized solution for such products according to some standards like API 5l, ASTM A 53 or DIN/SEP 1925. But some standards like API 5L together with Appendix F SR17.1 " Supplementary Nondestructive Inspection" , or IPS-M-PI -190(1) still insist on 100% hydrostatic test besides of NDT and NDT must be followed after pressure test . For such products off-line eddy current testing after hydrostatic test is the optimum solution but also most of such plants have installed on-line eddy current as well . Leakage Flux testing is applied only in 2 plants for testing high quality seamless boiler tubes of small sizes . In 5 plants larger ERW pipes 8 to 24 inches are produced. Full body eddy current testing for pipes over 8 inches is not easy . Therefore , for pipes over 8 inches eddy current is used only for weld seam testing and this test despite of controlling the production process and testing the weld cannot be replaced for hydrostatic test . In one plant on-line eddy current is used successfully to test thick wall pipes up to 12 mm and diameter up to 14

inches but this test is only weld inspection by segment coils. In these 5 plants large size pipes usually over 24 inches are produced by longitudinal or spiral SAW welding .In 2 plants who produce large size pipes according to AWWA all production is tested by on-line UT that is not required by the standard but they believe it is feasible for them to do it and in some cases is required by the customers' specification . In all these plants who produce API or IPS pipes due to thick tube walls all pipes are tested by off-line automatic ultrasonic systems after hydrostatic testing . Additionally the pipe ends and any areas that have been marked by UT system as defective as well as all repaired welds are tested by film radiography. Lamination test by UT is also executed in all these plants according to the requirements. Pipe ends for surface cracks are tested by MT or PT. In 2 plants real-time Radioscopy has been installed which in a new modern plant it is used to test 100% of the welds of large pipes and in the other plant it is applied only as a random test for welding process control . But in both plants due to the requirements of IPS , Ultrasonic Testing and Film Radiography is implemented as well .

CONCLUSION: Besides of technical and commercial evaluation, experimental survey has shown that by selecting a proper NDT technique and testing the pipes in proper stage of production, the following benefits will be obtained;

- Standard and highly quality zero defect products will be produced that will in cosequence will create a good reputation.
- the production quality will be monitored during production as real time process . This will decrease the scrap to minimum that will consequently increase production speed and decrease the production cost .
- The investment for testing facilities will be compensated within a certain period .

For optimization in selecting suitable NDT technique the following principles and priorities should be considered :

- As far as possible, only on-line test must be implemented. If on-line test is not possible or cannot fulfil the requirements, only off-line test can be an alternative . But experience has proven that in case of necessity to have off-line test, in long term the combination of on-line test is the most feasible choice .
- the eddy current test is the most feasible technique and must be considered as the first choice always if possible to fulfill the requirements . Otherwise the next alternative will be Ultrasonic Testing .
- As far as possible RT must be avoided but is some cases at least for pipe ends there is not any alternative .
- Leakage Flux testing is the most expensive test and should be considered as the last choice that should be used only on high quality expensive tubes.

Table 1 - Comparison of NDT methods for testing pipes

Fulfilling the requirements of Standards	EC	UT	RT	LF	MT	PT
API 5L (Oil & Gas Pipes)	++	+++	+++	+++	+	+
SEP 1917 (Pipes Quality Calss I)	++	+++	+++	+++	+	+
SEP 1915 (Pipes Quality Class III)	+	+++	+++	+++	+	+
SEP 1925 (Replacement of Hydrostatic Test)	++	++	+	+	-	-
ASTM A 53 (Pipes for general applications)	++	+++	+++	+++	+	+
Types of Defects						
Surface Defects	+++	++	+	+++	++	++
Internal Defects for thin material (below 5 mm)	++	+++	+++	+++	-	-
Internal Defects for medium thickness (5-15 mm)	+	+++	+++	++	-	-
Internal Defects rfor thick material (over 15 mm)	-	+++	+++	-	-	-
Possibility to compensate noise due to:						
Surface roughness of pipes	++	+	++	++	-	-
Polygon effects	++	+	++	++	-	-
Weld displacement	++	+++	++	+++	-	-
Other Advantages						
No consuming material	+++	-	-	++	-	-
Test Speed	+++	+	-	++	-	-

Reproducability of test results	+++	+	++	+++	-	-
Test in high temperatures	+++	-	-	+	-	-
Dimensional Checks	+	+++	-	-	-	-
Distinguish between inside and outside surface defects	+	+++	+	+	-	-

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EC	Eddy Current Testing	+++	Very Good
UT	Ultrasonic Testing	++	Good
RT	Radiography/Radioscopy	+	Possible
LF	Leakage Flux Testing	-	Impossible
MT	Magnetic Particle Testing		
PT	Penetrant Testing		

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