# Non Destructive Inspection of Oil Country Tubular Goods; Why & When?

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ABSTRACT

Deep holes and high pressures with their related problems have created a demand for better quality tubular goods unknown but a few years ago. The author outlines recent approaches to inspection methods and takes into account the economy of inspecting. However, no single non-destructive test can be expected to reliably measure all the properties. Further, the inspection must insure adequate service life, and it must have a proven correlation between the properties inspected and the performance properties of the pipe. Defects and defect evaluations are explained along with their effect on pipe quality.

## INTRODUCTION

In recent years, both the oil and steel industries have had to face the problem of developing suitable materials for drilling and producing wells beyond 20,000 ft. Because of the high pressures encountered at these greater depths of penetration, this year-by-year increase has added many problems in producing suitable oil country tubular goods. In some cases design factors for tension, collapse, and burst have had to be lowered. Furthermore, yield and tensile strengths have had to be increased for resistance to collapse and burst; and heavier wall thicknesses and larger couplings have had to be designed for greater and more efficient joint strengths. Too, with higher physical properties obtained by using alloys and/or quench and tempering, the age old problem of corrosion pitting and stress-corrosion cracking has become more evident.

During the past few years, there have been numerous cases in which service failures have occurred in the high strength grades of tubular goods and which were directly attributed to surface defects that were either inherent in the steel or introduced during manufacture or developed by subsequent usage in the field. Some failures have been extremely expensive; and, as pipe strength increases and applications have become more critical, it is only natural that steel quality and surface defects of all types should become a matter of much concern to the driller and producer. Thus, to protect himself the operator in his concern for quality material must first ascertain if possible the known conditions: temperatures, pressures, hole size, depths and straighness, etc. From this information he can readily determine the pipe program, i.e., size, weight, grade, range, etc. He may wish to use alloy steels in place of quenched and tempered steels or vice versa. However, the greatest unknown in his program is the surface quality of his material, and He must either trust to the integrity of the manufacturer or decide to employ the service of a disinterested third party to represent him as an inspector. The decision to employ non-destructive inspection is an important one because lack of familiarity with available inspection methods now offered commercially frequently lead to mis-use, and such mis-use develops prejudices which are difficult to overcome. These prejudices in turn delay the acceptance of other proven methods which could effectively reduce costs and improve operations. Furthermore, in some cases, the operator has not been informed of the possibilities of inspection; and, as a result, costly maintenance and service failures are tolerated when they could be greatly reduced both from a cost, safety and failure standpoint.

## LIMITATIONS OF NON-DESTRUCTIVE INSPECTION

First, it should be pointed out that no single non-destructive test can be expected to measure reliably all the properties of the material being inspected. In most cases, several separate types of non-destructive tests are required to supplement each other in order to determine all the properties which may influence service life. To date, there is no such thing as a general non-destructive test applicable to every kind of material.

Secondly, non-destructive tests differ from the usual methods employed in industrial "process or quality control." Process control limits the chemical composition of the material, structure, physical properties, dimensional tolerances, etc. These all tend to insure a consistently high quality and uniform product. However, it does have its limitations: some defective material can be produced under the best of quality control methods, and, for some applications, such defective material must be detected by other means, i.e., non-destructive inspection.

As much as one would like to think differently, there is a serious and definite lack of specific information on the influence of defects upon the strength and service ability of engineering materials. Non-destructive inspection cannot supply all of this information for it can only be obtained from either destructive testing and/or operating experience. Where material standards — such as the API standards on Oil Country Tubular Goods and others — have been established. The injurious types of defects are briefly defined; thus any one of many non-destructive types of inspection may suffice, providing the type of inspection selected or employed develops a proven correlation between the property actually inspected and serviceability of the product.

In present standards fail to give reliable information about the probable service performance of tubular goods then non-destructive inspecting becomes not only uneconomic but unrealiable. So in evaluating non-destructive inspection methods, it is of the utmost importance to make a distinction between the reliability of the inspection method and the judgment exercised by the inspector. Thus, the inspection method employed is no better than the inspector's knowledge, experience, and judgment. The inspector must be able to evaluate, with full understanding, the inspection results of the service to which the pipe is to be subjected.

Although the cost of non-destructive testing may seem high to some operators, a clear evaluation of the results will show that its real value lies in worthwhile cost reductions of shut down time, repairs, replacement and production losses. And further value of non-destructive inspecting lies in the practical application of the test to

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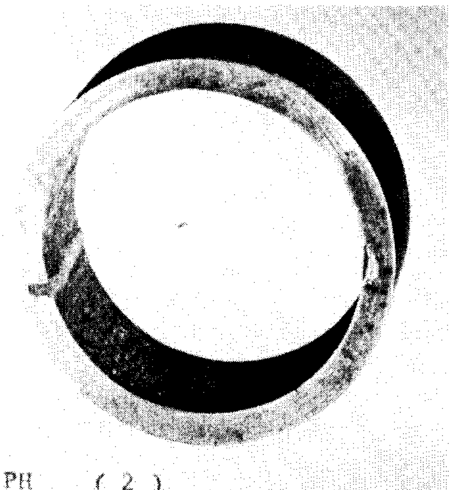

PHOTOGRAPH ( 2 )

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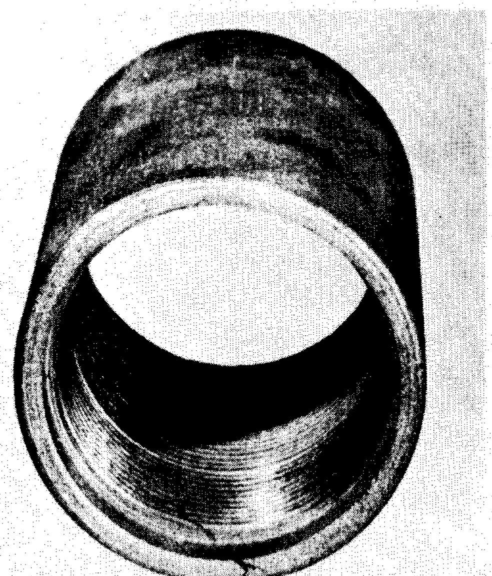

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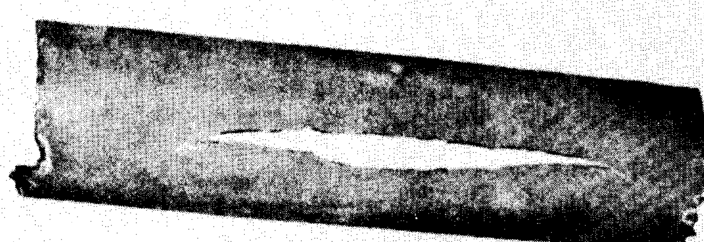

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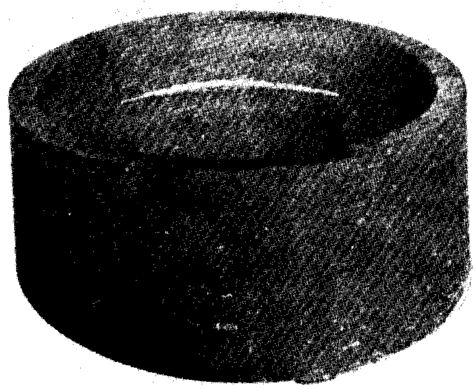

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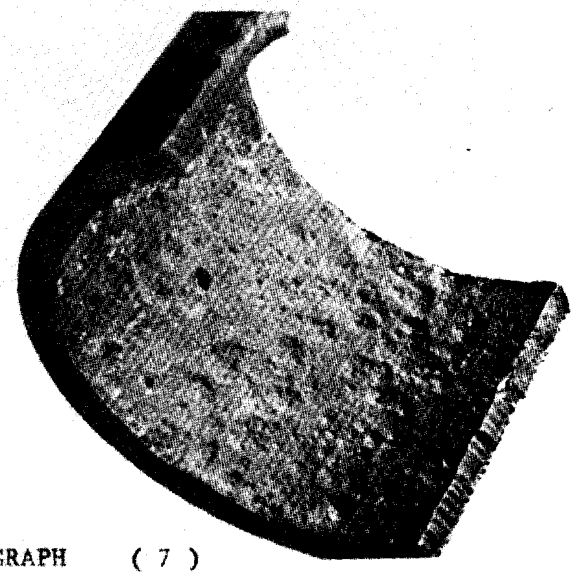

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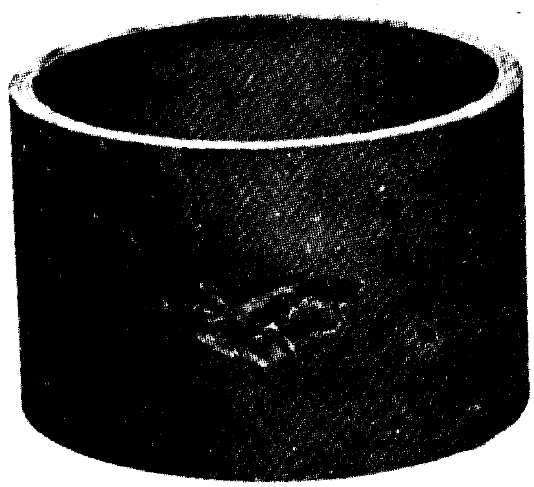

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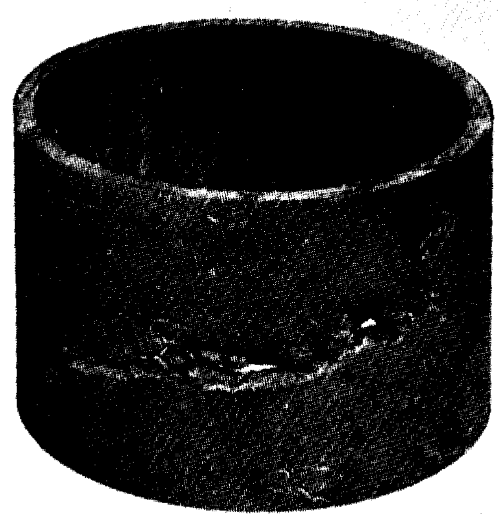

PHOTOGRAPH ( 9 )

the conditions under which the material must perform under normal conditions and be failure proof. Needless to say, however, when operating experience has shown that the usual forces causing failure are of little consequence (H-40 and J-55 material), it is useless to apply relatively high expensive non-destructive tests. The value of non-destructive testing must be designed for individual or specific problems relating either to conditions in the well or to the material being used in drilling, casing, or producing the well. For these reasons an attempt will be made to briefly describe the practical applications of some of the acceptable methods of inspection used presently in the field.

## MAGNETIC PARTICLE INSPECTION

Magnetic particle inspection of new and used tubular goods is one of the oldest of the later day developments in the field of non-destructive testing. In both the field and the mills it has been and still is the most common method used for determining the presence of injurious surface defects, such as seams, slivers, cracks, laps, rolled in slugs, and the like in casing and tubing.

The principle of the magnetic particle form of testing is based upon the fact that the permeability of steel is very markedly affected by the presence of any surface defect which destroys the magnetic continuity. Thus, defective areas always possess a lower magnetic permeability than sound material.

When the pipe has been properly magnetized, the magnetic lines of force spread out and detour any area of low permeability (defective area); then, after this detour, the lines tend to resume their original path. However, in detouring, the distorted lines of force enter the atmosphere in order to bridge the defect, and The poles created will attract and hold finely divided iron powder brought into the vicinity of the area of low permeability and will outline the defect so it can be seen without aid.

The method of magnetization must be carefully selected so it will establish lines of magnetic flux transverse to the possible direction of the defects. In other words, if the line of force is applied in a longitudinal direction, transverse defects are almost the only defects which can be detected. Conversely, if the force is applied in a transverse direction, the only defects which will be visible will be those lying in a longitudinal plane. In either case, defects will be detected if they lie in a plane approximately 45° to the applied line of force.

Two methods of force application are employed; one is the continuous method in which the magnetic powder is applied while the magnetizing force is still flowing, and the other is the residual method in which the magnetic particles are applied after the magnetizing force has ceased to flow. The effectiveness of the residual method depends upon the strength of the magnetic retentiveness of the grade of steel under test.

After the test piece has been properly magnetized, magnetic particles are applied by either the dry or wet process. The dry powder method is more commonly used because of its adaptability to oil field conditions; and the dry magnetic powder is applied with a hand air bulb or with an air gun and is evenly applied to the entire circumference of the pipe, over its entire length. On the other hand, the wet method employs the use of magnetic particles suspended in a solution of light oils; the solution is sprayed or flowed gently over the surface until an indication is developed. Then, for the detection of small cracks — particularly those located in upsets, thread roots, recesses, etc. — a fluorescent medium is employed, and the inspection is concluded with the application of an ultra violet or black light.

All these methods are about equal in their effectiveness and possess about the same limitations. However, the principle objection to the magnetic particle type lies in the fact that its effectiveness as an inspection instrument is confined to surface or near surface defects.

## ELECTRO MAGNETIC INDUCTION METHOD

Electro magnetic induction methods have been applied to the inspection of drill pipe and tubing for about the past ten years. The method of inducing a magnetic field into the pipe differs, but in most cases the test force magnetizes the pipe at or near its saturation point. The surface of the pipe is then explored for magnetic flux emanations, and the generated signal from changes in the magnetic field caused by the presence of defects is usually amplified and recorded in various ways for interpretation. Here, again, it is fortunate that the steels commonly used in the oil industry are strongly magnetic and that the magnetic permeability of these steels are very markedly affected by the presence of any defect which is of sufficient magnitude to destroy the continuity of the magnetic lines of force. The electro magnetic induction method reveals that it takes but little to disrupt this continuity when measured by suitable electronic devices. This statement has been conclusively proven by a correlation of the electronic recordings with a microscopic and metallographic examination of defective material.

## VISUAL AND OPTICAL INSPECTIONS

If the inspector possesses normal vision, it is a relatively easy matter to inspect the outside surface of any tube. And when one considers the rates of production, etc., mill inspectors do an extremely good job of inspection.

Critical inspection, however, requires optical aids, and complete detailed visual inspection is feasible only if each area is scanned by the spot of "clear vision" of the eye. Of these aids, optical magnifiers provide a means of compensating for the limits of visual acuity of the human eye, by enlarging small discontinuities. Inspection companies were the first to recognize the advantage of optical aid and introduced, to the field inspection of tubular production, the tube wall telescope which permits, under optimum viewing conditions, the direct visual inspection of the inside surface of the tube. The instrument in itself consists of a series of telescopic lenses made up in segments and with an objective lens on one end with the viewing lens on the other. Suitable lighting is installed in the head of the telescope, and a camera attachment permits an inspector to make a photographic record of his findings.

## HYDROSTATIC TESTING

Pressure and leak tests simply employ fluids under pressure to apply stress to the part as a test of material strength, or they may be applied as a means of revealing defects by the flow of fluids through them. Such pressures can be applied to the outside surfaces of casing to determine its resistance to collapse, or they can be applied internally to determine its resistance to burst.

This test (internal hydrostatic pressure) is recognized in the industry as a "proof" test of the material strength when tested to a pressure whose stress is 80 per cent or higher of the minimum yield strength. Because the internal hydrostatic test applies a stress in the direction of the lowest physical properties, acceptance of material by this test conveys some direct assurance that the length of casing or tubing will be resistant to bursting, and further, an indirect assurance of its resistance to collapse and tension. Hydrostatic tests applied internally are commonly used in the mill and in the field to test tubular goods. Such an application is also being used on casing and tubing made up in the well during the running and before bringing the well into production. These tests reveal leaky joints and/or defective material.

The most common method of field hydrostatic testing is accomplished simply by screwing a plug into the coupling and a cap onto the field end threads and having suitable connections for admitting water and releasing entrapped air. Then pumps mounted on mobile units apply the specified hydrostatic pressure for the required interval of time.

However, as an inspection instrument, hydrostatic testing is limited to the determination of the resistance to leakage at the coupling to pipe connection. But, on casing and tubing this test indirectly reveals the accuracy of the threads, the amount of make-up, and the application and quality of the thread lubricant.

## MECHANICAL GAGING TESTS

Gaging and calipering are the oldest of non-destructive tests. These tests are simple and are characterized by measurements of physical dimensions and surface finishes.

In the inspection of oil country tubular goods, gaging consists of measuing the outside diameter and wall thickness. The only check made on the inside diameter is, of course, the drifting of the entire lengths or ends with a mandrel slightly smaller than the nominal inside diameter.

The threads measurements are more precise and involve accuracies in measurements to 0.001 in. Extreme care must be exercised, because the tolerances on lead, taper, and height are expressed in thousandths of an in. and any error in the gages or gage manipulation would seriously impair the effectiveness of the inspection which is conducted on the pipe rack, prior to running the casing or tubing in the hole.

Another common type of tool for gaging or calipering is the mechanical wear gage designed to measure inside surface irregularities of used casing and tubing after it has been run in the well. Where corrosion is present, the gage is usually run at periodic intervals in order to ascertain the amount of corrosive or errosive penetration of the pipe wall.

## HARDNESS TESTS

In the field, considerable hardness testing is being done to ascertain the ductility and, indirectly, the physical properties of the pipe. These tests are important in the application of tubing in corrosive media or in a situation in which stress cracking is a factor in the service life. Usually this test is applied by establishing the "best" hardness range, and any lengths not falling within the range are directed to wells with less severe service conditions. Several reliable portable testers are now being manufactured, and their results compare favorably with laboratory bench models.

## TYPES OF DEFECTS

No reputable manufacturer wants defective material to reach his customers, but despite the best organized quality control programs some defects escape detection at the mill. Shown are some defect examples which were found by non-destructive inspection in the field:

Photograph 1 shows an outside seam extending through the upset of a joint of tubing. The depth of defect exceeded the allowable 12-1/2 per cent of the nominal wall thickness. The defect was not visible until inspected by the magnetic particle method.

Photograph 2 shows an inside score and crack in tubing penetrating the wall thickness to a depth of 76 per cent. This defect was found by the electro-magnetic induction method. Ordinarily this defect would have been passed by as being of little consequence.

Photograph 3 shows an outside seam on a tubing coupling in a critical area. Seams of this type are conducive to failure.

Photograph 4 shows an inside seam on a casing coupling. The seam extends from the recess face through the perfect thread length. Located in a critical area this coupling would probably failed us service.

Photograph 5 illustrates the failure of tubing under hydrostatic test pressure. The failure occurred along a tight but deep outside seam.

Photograph 6 shows an inside fatigue crack on grade E drill pipe. This crack was found by the electromagnetic induction method and was not visible to the eye. In all likelihood, this drill pipe would have failed within a matter of a few hours of drilling time, and the failure would have resulted in a fishing job.

Photograph 7 shows a good example of corrosive pitting without fatigue damage in grade E drill pipe. The maximum depth of pitting exceeded 25 per cent of the nominal wall thickness and was judged unfit for further service.

Photograph 8 shows a mechanical pit on grade E drill pipe. This defect was caused during its manufacture. The slug which had been rolled into the pipe wall fell out after being in service. The pipe was discovered upon inspection, and the discovery prevented a wash out.

Photograph 9 shows a wash out after a fatigue crack had penetrated the wall thickness and had allowed the drilling mud to wash through.

The defects illustrated herein are of the type not commonly found by visual inspection methods; yet each of these represent a possible failure in the tubular material. These defect illustrations are not isolated cases but are quite common to that small percentage of defective material found upon field inspection. When one considers that millions of dollars are spent to drill case and produce our wells, one can not believe that it is good engineering practice to invite disastrous failure by accepting material whose only criteria of acceptance is based upon ordinary quality control methods.

## CONCLUSION

The value of non-destructive inspection lies in the practical application of the test to the conditions under which the material must perform under normal conditions and under proof against failure. The non-destructive inspection must be designed for individual or specific problems related to conditions in the well or to the material being used in drilling casing or producing the well. If non-destructive inspection is to be not only reliable, but economical, knowledge of the conditions under which the tubular goods must perform and knowledge of the inspection technique to be employed to obtain the best results are paramount.