Diagnostic Tools for Evaluation of Quality of Tabular Goods and Sucker Rods

By FREDERIC D. SEWELL
Humble Oil and Refining Company

INTRODUCTION

The large expense normally incurred with replacement or repair of defective tubular goods in deep oil and gas wells provides excellent economic incentive to insure that the most effective inspection be used within practical limits. Inspections of new and used tubular goods performed to avoid running defective pipe and expensive failures are estimated to have cost the petroleum industry well over $8,000,000 in 1963; those associated with ordering and using tubular goods inspections should insure that each inspection dollar is earning money rather than being just another expense item considered necessary on critical pipe strings.

TYPES OF DEFECTS

Present manufacturing methods can result in production of tubes with several types of defects; despite mill efforts to detect and reject defective tubes using high-quality inspection systems, some defects may escape detection.

Fig. 1 illustrates a mill slug which is caused by the impression of foreign material into the tube wall during production. Slugs may exist on the inside or outside of a tube wall and may have nearly any configuration.

Seams and overlaps are fissure-type defects on the inside and/or outside of a tube wall and are normally oriented about parallel to the longitudinal tube axis. An overlap may be almost parallel to the tube surface with one face of the fissure extending over the other face, whereas the seam penetrates the tube wall in a radial direction. Fig. 2 illustrates an overlap in a pipe which is marked by an accumulation of magnetic particles.

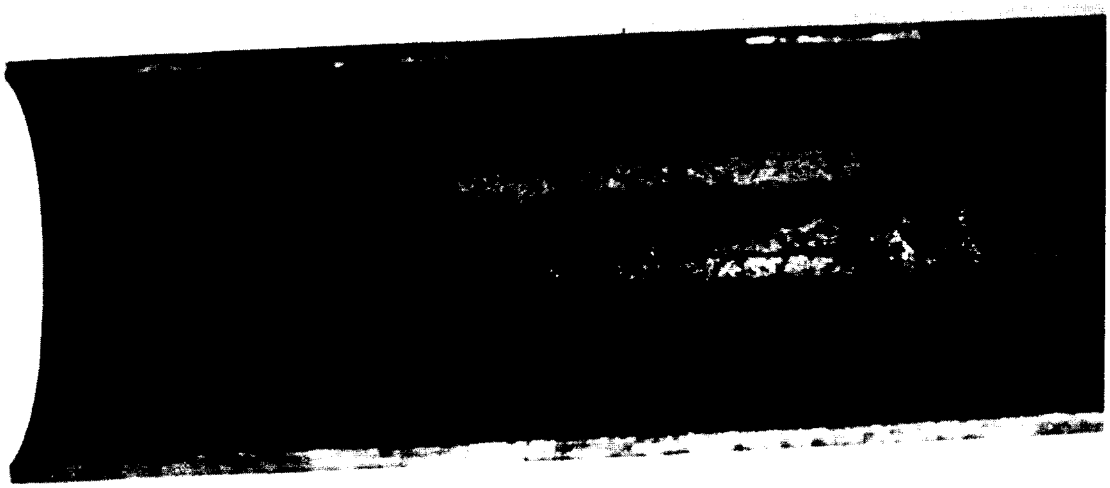

FIG. 1 - MILL SLUG

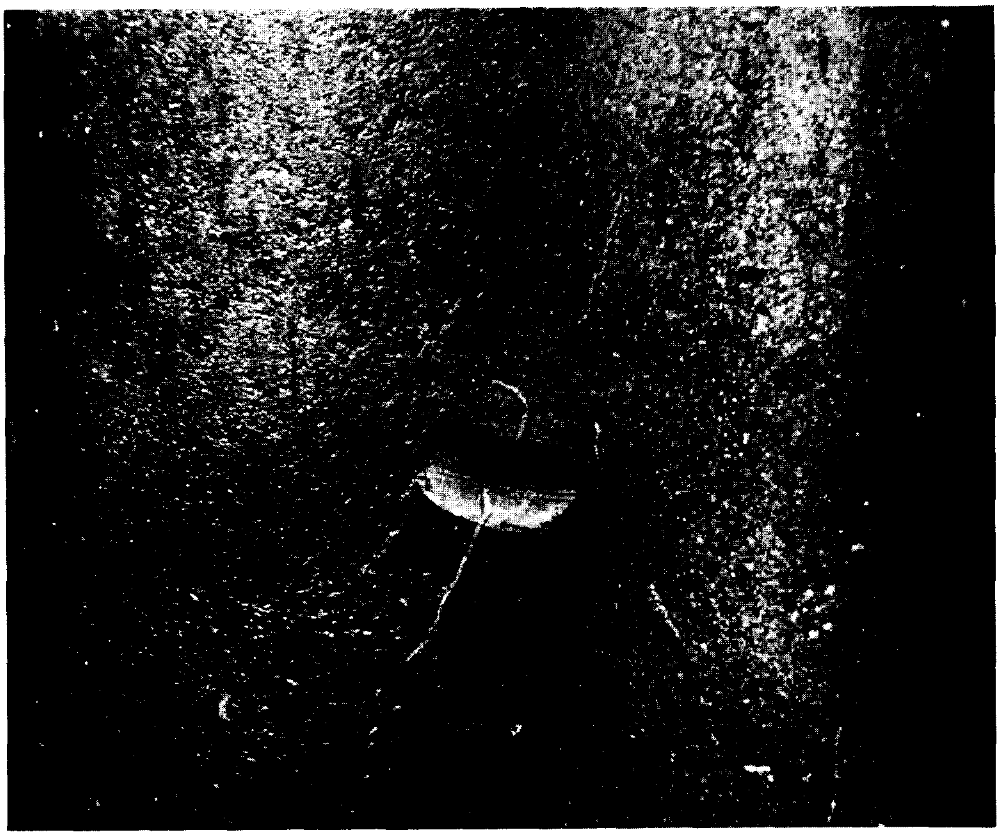

FIG. 2 - MAGNETIC PARTICLES SHOWING OVERLAP ON PIPE

The quench-and-temper heat treating process requires quenching steel tube almost instantaneously from about 1,600 F to 150-250 F which can result in internal stresses large enough to crack a steel tube.[1] Fig. 3 illustrates a quench crack detected in the threaded end of pipe. Failure to detect hazardous defects may result in unsatisfactory performance of tubular goods such as illustrated in Fig. 4.

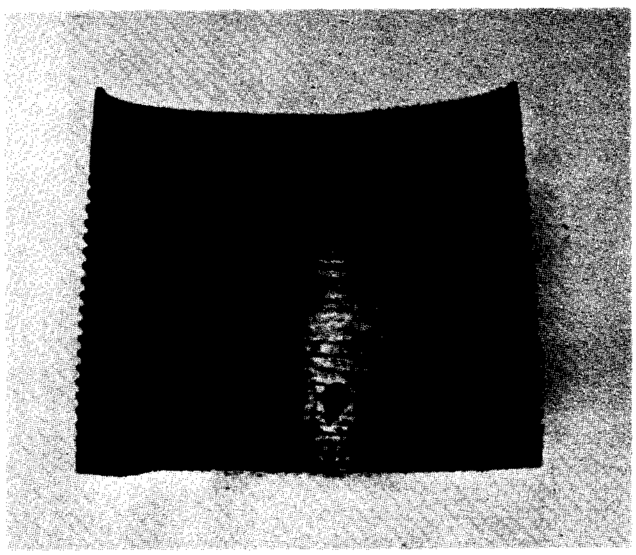

FIG. 3 - QUENCH CRACKS

DEFECT DEPTH LIMITS

A paradox to this scientific inspection business is that the question of what constitutes an actually dangerous defect is currently unanswered. The API specifications require detection and removal of defects with depths from 5 to 12-1/2% of the wall thickness of P-105 and P-110 grade tubular goods and rejection of all grade tubular goods with defects exceeding 12-1/2% of the wall thickness.[2,3]

The API specification disregards the notch sensitivity of the material and the shape and orientation of a defect or stress raiser. The stress concentration that occurs at the root of a crack may cause actual fiber stresses much larger than the calculated nominal fiber stress based on loss of cross-sectional area due to presence of a notch.[4]

In the past, the Industry has largely considered the effect of stress concentrations negligible in determining tolerable defect limits on the basis that tubular goods are ductile materials subjected to static loading; however, tubular goods loads in most wells are dynamic rather than static due to pressure and temperature fluctuations. The high ductility, upon which the Industry has depended for years to prevent failure by yielding and redistributing the stresses at cracks, may be inadequate in high-strength materials. The economic significance of determining how deep a defect can be and yet not cause failure, is increasing with increasing well completion depths.[5] Several inspection methods are available which, if properly employed, will detect defects as currently defined by API specifications.

FIG. 4 - BURST FAILURE OF CASING

HYDROSTATIC TESTS

It is important that persons associated with the design and use of tubular goods strings recognize that a hydrostatic test is a material test but not an inspection. Mill hydrostatic tests are generally limited to detecting gross defects; many harmful defects can pass a hydrostatic test without detection. The mill hydrostatic test stresses a tube for only one cycle, whereas severe service conditions subject a tube to cyclic stresses which may cause a crack to propagate.

Tests on tubular goods with artificial defects milled in the tube indicated that a single hydrostatic test to 80% of yield strength may not detect defects with depths equal to 35% of the wall thickness. Subjecting these defective tubes to cyclic pressure caused failure and indicated that these are harmful defects. An evaluation of hydrostatic testing indicated that single hydrostatic tests not only failed to detect many hazardour defects but also caused some undetected defects to become larger.[6]

VISUAL INSPECTION

Visual inspection, a useful inspection method which is often overlooked, provides an effective means to detect:

1. Gross mill defects such as large seams, slugs, pits, and cracks
2. Poorly machined threads
3. Shipping or handling damage to the pipe body, connection, and threads.

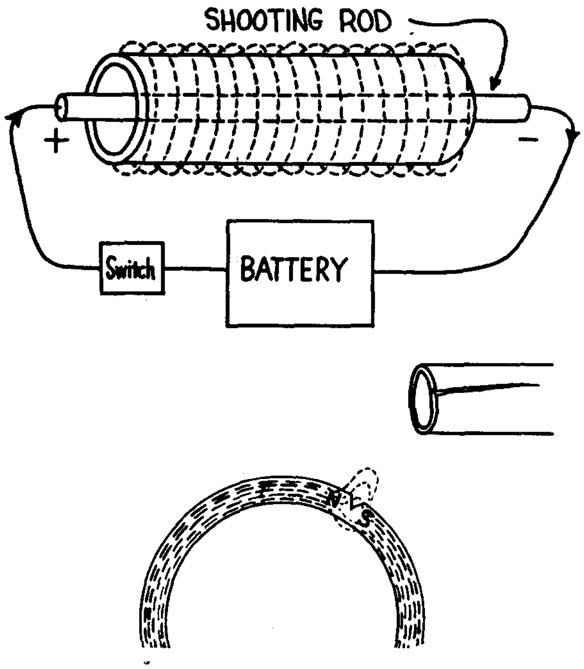

FIG. 5 - PRINCIPLE OF MAGNETIC PARTICLE INSPECTION

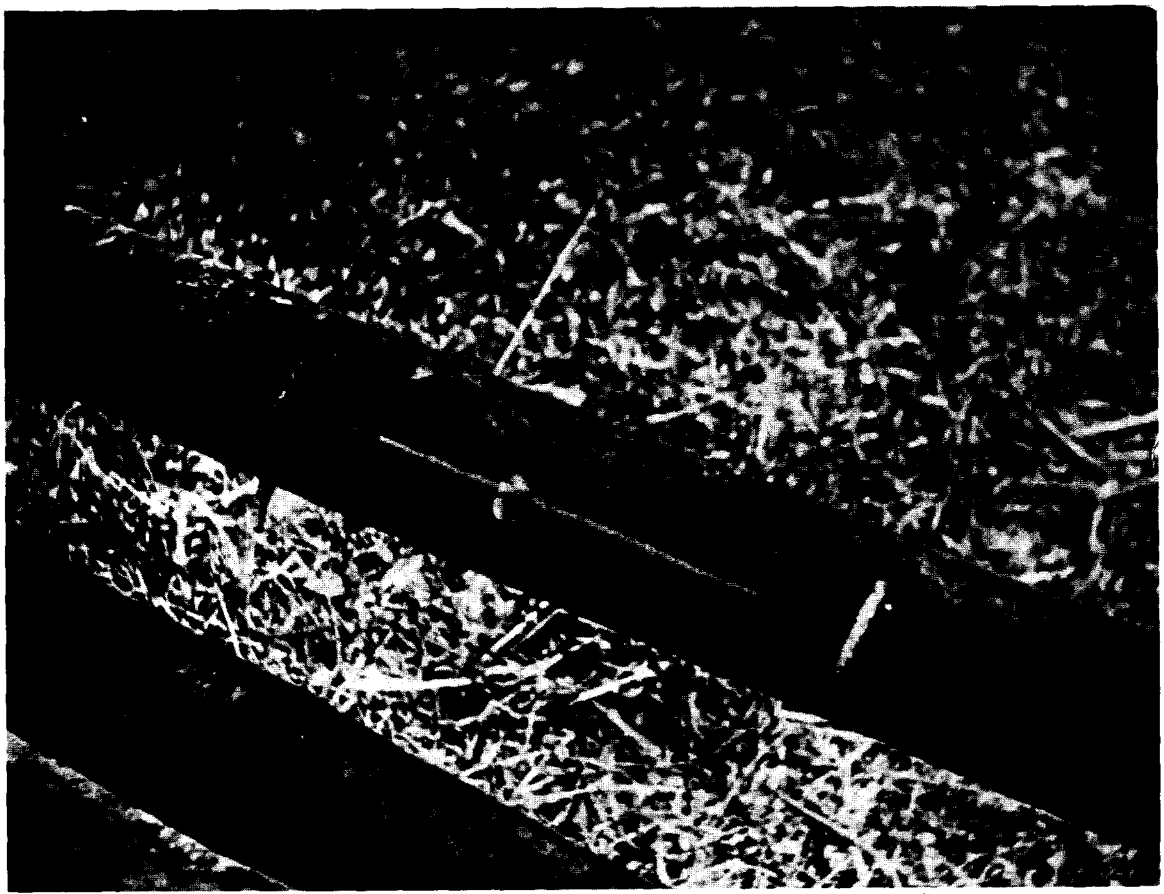

FIG. 6 MAGNETIC PARTICLES SHOWING LONGITUDINAL CRACK

MAGNETIC PARTICLE INSPECTION

Magnetic particle inspection is an effective diagnostic tool for detecting tight cracks and other fissure-type defects at or near the tube surface. Fig. 5 illustrates the basic principle employed in magnetic particle inspection. Direct current flowing through an insulated conductor or shooting rod inside the tube induces a transversely oriented, residual magnetic field. This field will maintain a uniform flux density pattern within the tube wall if the wall thickness is uniform. A longitudinal discontinuity in the tube wall, such as a crack or other defect, will alter the flux pattern causing a flux leakage field around the defect.

Dusting the defective tube with magnetic particles will result in an accumulation of particles attracted by the field which will pinpoint the defect. The photograph in Fig. 6 shows an accumulation of magnetic particles which marks a longitudinal crack in the pipe body; the large magnetic particle build-up indicates that this is a deep crack. Investigation to determine crack depth is performed by grinding to the bottom of the crack and then measuring the depth of the grind using a pit gauge.

Magnetic particle inspections are accomplished using wet or dry magnetic particles. The dry-particle method, the results of which are illustrated in Fig. 6, provides a more sensitive inspection for detection of subsurface defects and is more effective on rough surfaces than the wet method. The wet method employs fine magnetic particles suspended in oil or water. The mixture is normally flowed over the tube OD. Magnetic particles coated with fluorescent material and used in conjunction with a black light, produce a glow at each

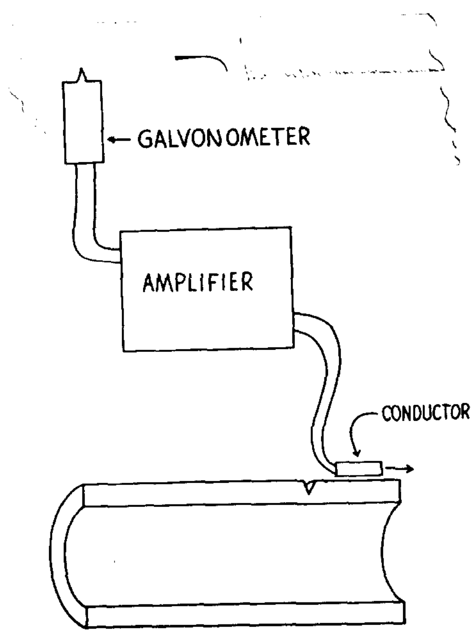

FIG. 7 - PRINCIPLE OF ELECTROMAGNETIC SEARCH COIL (FLUX LEAKAGE) INSPECTION

accumulation of particles. This fluorescence facilitates visual detection of defects which improves the effectiveness of the inspection.[7]

Magnetic particle inspection is an excellent method for detecting cracks which penetrate the tube surface; it is less effective for detecting cracks which do not penetrate the surface and generally will not detect small deep-seated subsurface defects. The method permits use of relatively low-cost portable equipment.

ELECTROMAGNETIC INSPECTION

Flux Leakage Inspection

Systems have been developed which employ conductor shoes or search coils for detection of flux leakage fields to minimize dependence on human detection of defects. As shown in Fig. 7, current generated in search coils passing through a flux leakage field (caused by a defect) flows to an amplifier to strengthen the signal and then to a galvanometer which records the signal. An anomaly on the log, as shown in the illustration, will indicate presence of a defect in the pipe. An operator interprets signals on the log, and when he considers a signal significant, he pinpoints the defect and grinds the tube to determine the actual depth of the defect.

The flux leakage inspection systems employing search coils include two types which will detect defects as follows:

1. Corrosion pits and transverse defects
2. Corrosion pits, transverse defects, and longitudinal defects

In the first type of flux leakage inspection system, direct current flowing through a coil around the pipe's circumference induces a longitudinal field in the tube which causes flux leakage fields to be established at each pit and transverse defect. The conductor shoes or search coils detect pits and transverse defects; however, these inspection systems will not detect defects which have only longitudinal direction.

The second type of inspection system detects corrosion pits and both transverse and longitudinal defects. The system induces a transverse magnetic field in tubular goods for longitudinal defect detection and induces a longitudinal magnetic field for detection of corrosion pits and transverse defects.[8] The system actually performs two inspections in one pass, and the order of these inspections may be reversed.

Eddy-Current Inspection

In eddy-current or electromagnetic induction inspection systems, the tube normally passes through a varying magnetic field of a coil or an array of conductors carrying an alternating current. The alternating current magnetic field induces eddy currents in the tube. A defect will disturb the eddy-current paths which will be reflected in the actual impedance of the pickup coil. Careful measurement of impedance variations in the pickup coil permits detection of defects by indicating magnitude and phase differences of eddy currents caused by the defects.[9]

Eddy-current methods provide high-speed inspection and are adaptable to automatic operation. Detection of longitudinal oriented defects in tubular goods requires induction of current in a transverse direction which can be accomplished by passing pipe through a wire-wound current-carrying coil assembly.[10]

Eddy-current inspection can detect cracks, seams, overlaps, and changes in grain structure and hardness. Successful application of eddy-current inspection requires establishing the electrical relationship between hazardous defects, changes in grain structure, small flaws and other harmless variables, and their effects on a large variety of test circuits.[10]

Combining eddy-current and flux-leakage phenomena has provided an inspection system for detecting weld-area defects in electric-resistance-welded pipe. Induction coils induce magnetic flux in the pipe and transducers reciprocate across the weld on the pipe OD surface to measure signals induced by defects such as weld cracks and plate laminations in the weld area. Magnitude of the induced signal is a function of the area of the defect. Production line applications of this diagnostic tool require that the weld be trimmed flush with the pipe OD surface to eliminate air gaps between the pipe and transducers.[11]

ULTRASONIC INSPECTION

Ultrasonic inspection consists generally of transmitting electrically produced pulsed vibrations or high-frequency sound waves through an object such as pipe and observing for refractions or reflections of sound waves which indicate the presence of defects in the object. Transducers transmit high-frequency sound waves through liquid and metals at approximately the same speed as audible sound; however, the waves have almost no ability to travel through air and will be reflected from a surface just as audible sound (an echo) or light. Fig. 8 illustrates the principle of pulse echo ultrasonic inspection which is the technique normally employed in ultrasonic inspection of tubular goods and rods. The transmitting transducer and receiving transducer form one unit on the same side of the test specimen to permit measuring sound waves reflected from the surface of a defect in the specimen. Reflected sound waves cause a pip or vertical line on the cathode ray tube which indicates presence of a defect in the specimen. In the through-transmission ultrasonic inspection, the receiving transducer is normally located on the opposite side of the specimen from the transmitter to detect decreases of energy transmitted through the specimen caused when defects reflect sound waves.

Ultrasonic inspection requires a fluid coupling to transmit accoustical energy to the test specimen. The contact inspection method normally employs an oil film between the crystal and specimen; the immersed inspection method employs a column of water which varies from a fraction of an inch to several inches.[12]

Ultrasonic inspection is especially valuable for detection of deep-seated internal defects. Ultrasonic inspection is adaptable to fast automatic operation. Applications for this diagnostic tool include thickness measurement because access to only one surface is necessary.[13]

RADIOGRAPHIC INSPECTION

Radiographic inspections require transmitting X-rays or gamma rays through a test specimen and recording the resultant images on film or radiograph. X-rays have wave lengths ranging from 1×10^{-4} to 1×10^{-7}, that of visible light which permits X-ray

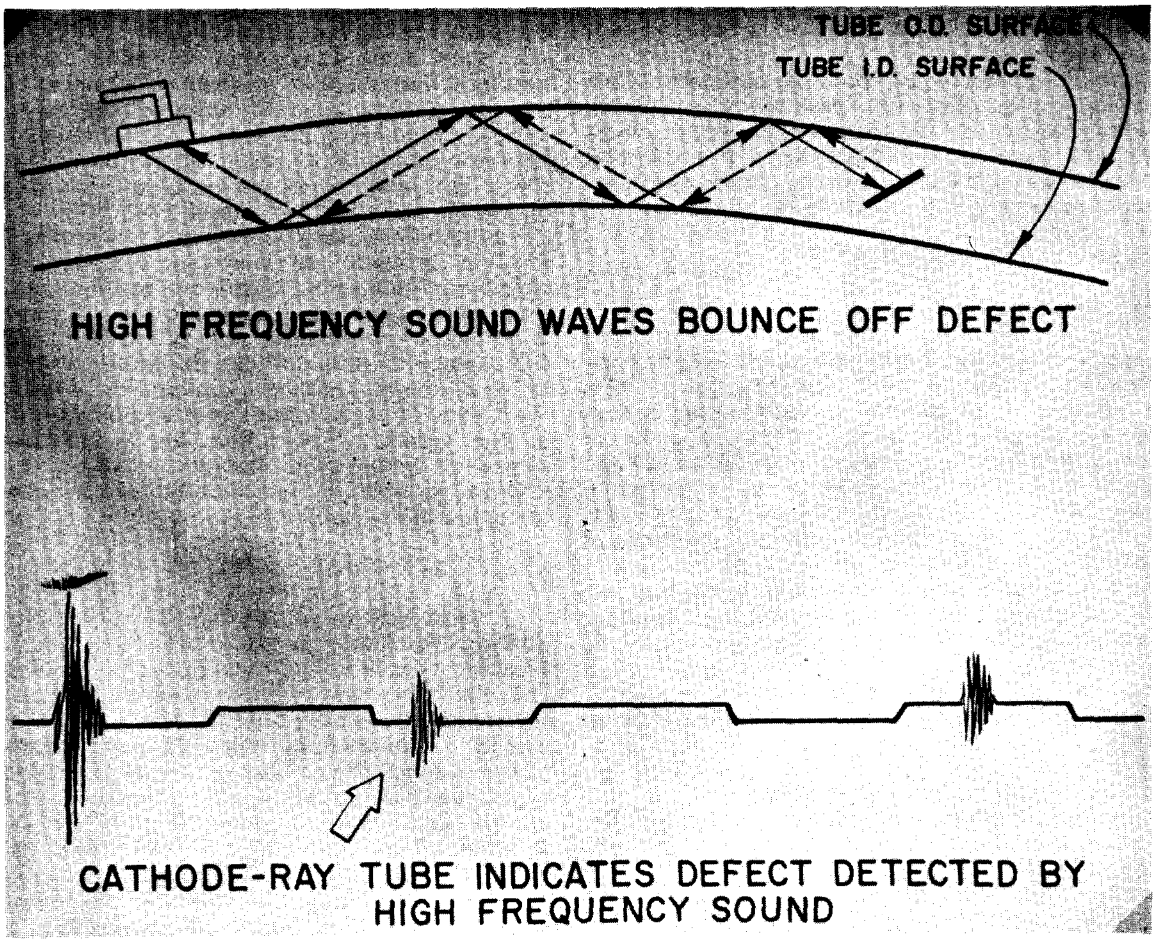

FIG. 8 - PRINCIPLE OF PULSE ECHO ULTRASONIC INSPECTION

penetration of opaque materials such as steel; gamma rays have even shorter wave lengths than X-rays and are produced by radioactive materials rather than by high voltage. Test specimens absorb some rays. The amount of radiation transmitted through the specimen depends on the energy of radiation, nature of specimen material, and thickness of the specimen. A void or defect in the test specimen reduces the thickness of metal to be penetrated permitting transmission of more rays than possible through the surrounding metal.[14,15]

Representation of the degree of radiation transmitted is actually a shadow picture. Dark spots on the radiograph indicate positions of voids or defects through which higher transmission of rays occurred; lighter regions on the film indicate less penetrable areas of the test specimen.

Detection of defects by radiographic inspection requires absence of material or presence of foreign material with energy transmission properties differing from those of the test specimen. If the defect does not affect the radiation transmission through the material, no image will occur on the film to indicate presence of the defect.[16] Radiographic inspection normally indicates presence of defects such as harmful weld porosity, voids, and inclusions; however, it may not indicate the presence of hazardous cracks.

FLUOROSCOPIC INSPECTION

Fluoroscopic inspection differs from radiographic inspection in that a fluorescent screen permits continual screen viewing of the X-ray image rather than observation on a film record. Fluoroscopy provides a fast, low-cost internal inspection of specimens in quantity production. Advantages of this diagnostic tool over radiographic inspection include its faster speed, elimination of film record, and lower cost. Inspection sensitivities approaching those of radiography can be accomplished in fluoroscopy.

Fluoroscopic inspection limitations are similar to those of radiography; fluoroscopy will detect voids or defects which adequately affect radiation transmission through the material but may not detect hazardous cracks. Effective fluoroscopic inspections require limiting scanning speed to a reasonable maximum and alternating inspectors to minimize fatigue due to continual viewing.

INSPECTIONS AVAILABLE FOR SPECIFIC APPLICATIONS

Table I presents inspections available for casing, tubing, drill pipe, line pipe, and sucker rods. The several types of diagnostic tools available for tubular goods and rods permit selecting the method that more nearly fulfills inspection requirements of each individual job. The user should first determine the economics of an inspection. If economic considerations indicate that an inspection is necessary, the user should weigh advantages of each diagnostic tool with factors such as the type tubular goods or rods, past and future applications for the pipe or rods, and specific inspection requirements.

TABLE I

INSPECTIONS AVAILABLE FOR SPECIFIC APPLICATIONS

Applications	Inspections Available
Casing, Tubing, and Drill Pipe	Electromagnetic Magnetic Particle Ultrasonic Visual
Line Pipe	Electromagnetic Fluoroscopic Magnetic Particle Radiographic Ultrasonic Visual
Sucker Rods	Electromagnetic Magnetic Particle Visual

As previously noted, inspection systems are available which will provide satisfactory inspections if properly employed; however, these diagnostic tools are not the final answer to our inspection problems. All of the currently available inspection methods have some advantages and some limitations. The work inspection companies are performing to improve diagnostic tools should result in the development of new improved inspection systems in the future.

CONCLUSIONS

Economics actually determine whether or not an inspection is necessary. Capital investment in tubing and casing commonly exceeds 25% of the drill-and-complete cost of most producing wells, and their failure can result in losses far exceeding the aggregate well cost. If conditions indicate that an inspection will reduce cost by minimizing pipe failure, an inspection probably is necessary.

We should insure that inspections are necessary and effective and that our inspection dollars do earn a profit; or in other words, we should insure that our inspections exemplify the familiar saying, "An ounce of prevention is worth a pound of cure."

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