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A Review on Boiler Tube Assessment in Power Plant using Ultrasonic Testing

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ABSTRACT- *A review was undertaken to correlate the non-destructive testing with condition assessment of boiler tubes. The evaluation included non-contact wall thickness measurement with EMAT technology plus internal oxide layer measurement with specialized ultrasonic. The existing tube removal criteria are treating each damage mechanism separately while in reality, a combined effect of wall thinning and the "degree of overheating" decides about true condition of a tube. The procedure that utilizes the results of both described NDT methods was developed for improved methodology to assess tube condition and to predict its remaining life. Detailed image can be produced with automatic system and it provides instantaneous results. To prevent unexpected disaster by crack propagation in boiler tubes, it is necessary to periodically inspect tubes of super-heater, re-heater and economizer. It is difficult to inspect all tubes from outside because most tubes are located at narrow space in a boiler. By using ultrasonic testing, sound energy is introduced and propagates through the material in the form of waves. As the discontinuity arrives in the wave path the part of sound energy is reflected back from the flaw surface. Travel time can be directly related to the distance that the signal travelled back from the cracked surface. This reflected wave signal is transformed into an electrical signal by the transducer and displaced in the screen. By knowing the velocity of the waves that strikes the cracks and produces high voltage ultrasonic energy in the boiler tubes can be easily predicted. By schedule maintenance, efficiency and reliability of boiler increases and can be prevented from disaster of the plant.*

Key Words: NDT, EMAT, Ultrasonic, sound waves, Acoustic waves.

1.0 INTRODUCTION

1.1 Nondestructive testing

Nondestructive testing (NDT) is a broad group of analytical methods used in industries and science in order to assess properties of metals, systems or components without causing damage. This form of testing does not change the item under inspection. This makes NDT one of the most valuable techniques in saving time and money in terms of troubleshooting, product evaluation and research. Nondestructive testing is also known as non-destructive examination (NDE) and non-destructive evaluation (also NDE) as well as non-destructive inspection (NDI).

1.2 NDT Test Methods

- Acoustic Emission Testing (AE)
- Electromagnetic Testing (ET)
- Neutron Radiographic Testing (NR)
- Radiographic Testing (RT)
- Thermal/Infrared Testing (IR)
- Ultrasonic Testing (UT) Vibration Analysis (VA)
- Visual Testing (VT)
- Guided Wave Testing (GW)
- Ground Penetrating Radar (GPR)
- Laser Testing Methods (LM)
- Leak Testing (LT)
- Microwave Testing
- Liquid Penetrant Testing (PT)
- Magnetic Particle Testing (MT)

1.3 Wall Thinning Measurement with EMAT

As boiler ages, corrosion and erosion causes the tube wall to become thinner until it cannot sustain the internal pressure. Weak (thin-walled) tubes should be replaced or repaired long before burst can occur. One common procedure for measuring the water-wall tube thickness is to grind or sandblast the fire side of the water-wall to expose a bare metal and use ultrasonic (UT) to determine the wall thickness. In addition, the conventional ultrasonic method requires a liquid couplant in order to transmit ultrasound wave into the metal and for that reason it is hard to automate. One of the goals of this research was to improve existing methods of tube evaluation therefore a feasibility of using EMAT (Electro Magnetic Acoustic Transducer) was investigated for specific conditions.

EMAT offers certain advantages over standard UT – no need for tube cleaning and couplant, therefore it brings a potential for significant cost reduction. The economic advantages of EMAT are best described by comparing it with standard ultrasonic thickness measurement. There are two ways that EMATs can generate elastic energy directly in the boiler water-wall. The first is via the "Lorentz force" mechanism where than their magneto-strictive counterparts. EMAT transducers can work with general-purpose ultrasonic instruments with certain modifications, most important being the adequate initial pulse, at least 400V.

1.4 Ultrasonic testing

Has an extensive range of tools and techniques to match every inspection challenge, from simple thickness measurement to fully automated inspections. Ultrasonic testing uses high-frequency sound energy to perform examinations and make measurements. Ultrasonic testing may be used for dimensional measurements, thickness, material characterization, flaw detection, and more. Multiple advances in ultrasonic have taken place in recent times, evolving from the conventional thickness application to the use of more advanced methods encompassing various modes and also large efforts are employed to develop new applications and technologies surrounding ultrasonic as a whole, while staying abreast to current industry practices and methods.

In general ultrasonic testing is based on the capture and quantification of either the reflected waves (pulse-echo)or the transmitted waves. Each of the two types is used in certain application but generally pulse echo systems are more useful since they require one sided access to the object being inspected

1.5 Basic principles

A typical pulse-echo UT inspection system consists of several functional units, such as the receiver, transducer, and a display device. A receiver is an electronic device that can produce high voltage electrical pulses. Driven by the pulser, the transducer generates high frequency ultrasonic energy as shown in fig. 1. The sound energy is introduced and propagates through the materials in the form of waves. When there is a discontinuity (*such as a crack*) in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen. Knowing the velocity of the waves, travel time can be directly related to the distance that the signal traveled. From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.

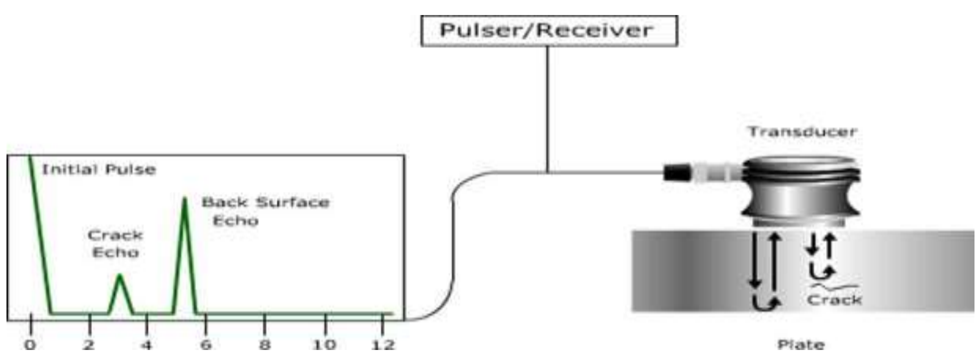

Fig. 1 pulse-echo UT inspection system [17]

1.5 Wave Propagation

Ultrasonic testing is based on the vibration in materials which is generally referred to as acoustic. All material substance are comprised of atoms, which may be forced into vibration motion about there are equilibrium position. Acoustic is focused on particles that contain many atoms that move in harmony to produce a mechanical wave. When material is not stressed in tension or compression beyond its elastic limit its individual particles perform elastic oscillation. When the particles of medium are displayed from their equilibrium positions internal restoration forces arise. This elastic restoring force between particles combined with inertia of the particles lead to the oscillatory motion of the medium.

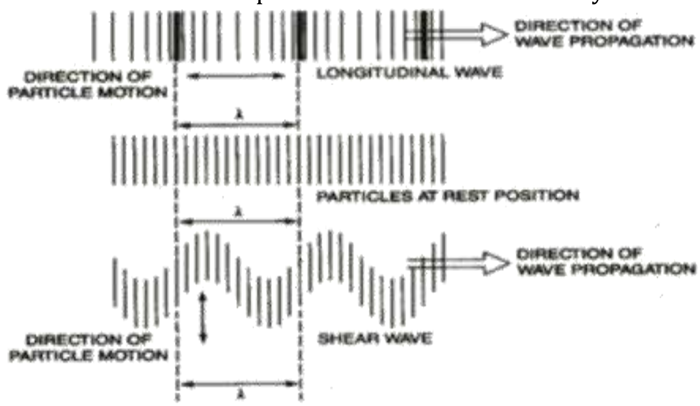

Fig.2 propagation of longitudinal shear waves [17]

In solid sound wave can propagate in four principal mode that are based on the way the particles oscillate sound can propagate as longitudinal waves shear wave, surface wave, and in thin materials as plate wave. In longitudinal waves the oscillation occuer in the longitudinal direction or the direction of wave propagation since compression and expansion forces are active in these wave, they are also sometime called density wave because material density fluctuates as the wave moves. Compression waves can be generated in gases, liquids as well as solids because the energy travels through the atomic structure by a series of compression and expansion movement In the transverse or shear waves particles oscillate at right angle or transverse to the direction of propagation and therefor are not effectively propagate in materials such as liquids or gasses shear waves are relatively weak when compared to longitudinal waves in fact shear waves are usually generated in material using some of the energy from longitudinal waves.

1.6 Modes of sound wave propagation

Sound travels in air by compression and rarefaction of air molecules in the travels direction in solids, sound wave travels by molecular vibration. Hence a number of sound waves are possible. Wave can be characterized by oscillatory pattern. Wave propagation is often described in terms of wave modes Surface (Rayleigh) waves travel at the surface of a relatively thick solid material penetrating to a depth of one wavelength. Surface wave is a combination of both a longitudinal and transverse motion which results in an elliptical motion. Surface waves are generated when a longitudinal wave intersects a surface larger than the second critical angle. Rayleigh waves are useful because they are very sensitive to surface defect. Plate (Lamb) waves are generated in material a few wavelength thick (thin plates) and similar to surface wave. Lamb waves are complex vibrational wave that propagate parallel to the test surface throughout the thickness. Lamb waves are generated when a wave hits a surface at an incident angle such that the parallel component of the velocity of the waves (in the source) is equal to the velocity of the wave in the test material.

1.7 Acoustic Waves

Among the properties of the waves propagation in isotropic solid material are wavelength, frequency and velocity. The wavelength is directly proportional to the velocity of the wave and inversely proportional to the frequency on the wave. The velocity of sound in certain medium is fixed where it is characteristic of that medium.

=Where;

: wavelength (m)

V: velocity (m/s)

F: frequency (Hz)

1.8 Wavelength and defect detection

In ultrasonic testing the inspector must make a decision about the frequency of the transducer that will be used in order to control the wavelength of the ultrasound used has a significant effect on the probability of detecting a discontinuity. A general rule a thumb is that a discontinuity must be larger than half the wavelength to stand a reasonable chance of being detected.

Sensitivity and resolution are two terms that are often used in ultrasonic inspection to describe a techniques ability to locate flaws. Sensitivity is the ability to locate small discontinuities. Sensitivity generally increases with higher frequency. Resolution is the ability of the system to locate discontinuities that are close together within the material or located near the part surface. Resolution also generally increases as the frequency increase.

The wave frequency can also affect the capability of an inspection in adverse ways. Therefor selecting the optimal inspection frequency often involves maintaining a balance between the favorable and unfavorable results of the selection before selecting an inspection frequency the material's grain structure and thickness and the discontinuity type size and probable location should be considered. As frequency

2.0 LITERATURE REVIEW

Vakhguelt et al. [1] this paper describe prediction of boiler tube remaining life by condition assessment of tubes with more efficient method. The authors have visited number of coal fired electric plant and found that a wall thinning and overheating major damage mechanism contribute in boiler tube failures. Scheduled maintenance of boiler tubes include ultrasonic measurement of wall thickness and find defective, it involves cutting tube section and performing metallurgical analysis for losses of original strength due to overheating of tubes. Research was undertaken with the objective and correlate the results of combined non-destructive (NDT) condition inspection of boiler tubes. Evaluation includes non-contact wall thickness measurement with EMAT technology plus internal oxide layer measurement with ultrasonic. First method shows the wall thickness of remaining tube and calculate total stress, and latter one has the potential to indirectly characterize microstructure degradation could be determine by the destructive analysis. The existing tube removal criteria are treating all damage mechanism separately, a combined wall thinning and the "degree of over-heating" decides about true condition of a tube. In this paper result of described NDT methods was developed for improving methodology to assess tube condition and predict the remaining life of boiler tubes.

Mandal et al. [2] Performed the experimental investigation on non-destructive testing of continuously stabilized material (CSMs) was studied ultrasonic pulse velocity instrumentation. Test was conducted on CSMs to check flexural strength and flexural modulus and their constrained modulus were recorded. The effect of compaction, curing time, and binder content was calculated . The result shows the P-wave velocity decreases with decrease in density where P-wave velocity increases with increase in curing time and binder content. A relationship R2=089 was observed between flexural strength and constrained modulus, and relation between flexural modulus and constrained modulus at 30% stress level also high R2=0.70. Non-destructive testing in thus proposed as a convenient and experimental method to determining the flexural properties of CSMs in comparison to destructive method to third-point bending beam tests

Bruce et al. [3] Has performed the experimental investigation on ultrasonic array in a single transducer that contains a number of individually connected element. Science few years have been increase in the use of ultrasonic array of non-destructive testing. There are some advantage of Ultrasonic array test as, increase inspection quality and reduce inspection time, increase flexibility over single element transducer methods, different function can performed by single array produce immediate image of the test structure. Ultrasonic array gives better result and less time consuming these have various advantages so the rapid uptake by the engineering industry. Public research on this is at wide range these describe new piezoelectric material, array geometry, modeling methods and inspection modalities. In this paper most relevant published work bring together on array for non-destructive evaluation application and also referring to use of array in medical and sonar field, The use of array in non-destructive evaluation is distinctly different challenges to other disciplines.

Schabowic et al.[4] has performed the experimental investigation on non-destructive technique using a non-contact ultrasound scanner, forth testing of fiber cement boards. This technique defect locating in usually unilaterally accessible fiber cement boards describe during their production. The methodology was verified through laboratory tests on specimen and trial on a production line. Reliability and suitability of this technique have been conformed.

Bompan et al.[5] Has performed experimental investigation on ultrasonic pulse velocity methods is a nondestructive test used to find elastic property of material, non-homogeneities and damages in structural element other application is the measurement of the stress state in a material. This paper addresses the use of ultrasound for the evaluation of stress in concrete structures. Increase of compression stress leads to higher velocities of ultrasonic waves, which proved the acoustoelastic effect this behaviour was not observed in longitudinal wave propagation. According to the change in velocities of the ultrasonic wave acoustoelastic coefficient were determined.

Maso et al. [6] Has performed experimental investigation the raw earthen material is investigated using ultrasound transmission method. This technique is effective at controlling the drying process of raw earthen materials. There is a linear relationship between the moisture content of earthen material and the ultrasound transmission speed near the hygrometric equlibrium, which increase during drying process. Ultrasound transmission speed is over 1100 m/s on this speed it reach to hygrometric equilibrium.

Ma et al [7] Has performed the experimental investigation ultrasound technique with jet pulse electrode position (JPE) for Ni-Al nanocoating. Scanning electron microscopy (SEM). Ni-Al nanocoating deposited by using ultrasound shows the minimum and most compact surface structure compared to other coating. The thicknes of coating were approximately 56 μm. Average atomic % of Al and Ni element in Ni-Al nanocoating prepared by the using ultrasound were approximately 21.4 at % and 47.5at %, respectively. Maximum kinetic energy was 916 m^2/s^2 during JPE-deposite Ni-Al nanocoating including ultrasound. In this case the shows that corrosion resistance was most efficient. The coating of Ni-Al prepared using ultrasound sustained the minimum friction coefficient and average friction coefficient was approximately 0.52. JPE deposited Ni coating presented the maximum friction coefficient.

Wang et al.[8] in this paper nondestructive, especially ultrasound testing method, used to detect concrete strength, compactness, cracks and other aspects. Test thickness of damage layer measured by ultrasound plane testing method. The variation in performance of the original specimen was significant with increased thickness. Relation is exponential between the damage layer thickness and original performance expected weight loss ratio. In the corrosion process, sulfate ions were transported into micropores and microcracks layer by layer and velocity diffused slowly from a surface.

Sahbal et al.[9] In this paper author experimental investigated on background cuff leak test(CLT) has been proposed a simple method predicting post-extubation stridor(PES), due to different cuff-leak volume and cut-off point between previous studies, the laryngeal ultrasonography(US) including measurement of air column width was used to predict PES. The aim of study was to evaluate the value of laryngeal US versus cuff leak test in PES. CLT and Laryngeal ultrasound both might have low sensitivity and PPV in predicting PES and it should be used with caution in prediction of PES.

Yang et al.[10] Has performed experimental investigated by the ultrasonic-assisted impregnation method Mn-Ce mixed oxides modified wheat straw chars were prepared and were employed to remove elementary mercury from flue gas. The effect of ultrasonic-assisted impregnation Mn/Ce molar ratio, Mn-Ce loading values, reaction temperature and main flue gas component such as SO_2, O_2, NO and H_2O on mercury removal using these catalysts were studied in a fixed bed reactor. The mercury removal mechanism was also discussed based on experimental result and characterization analysis.

Liu et al. [11] Has performed experimental investigation winding process of aramid fiber composites to enhance the adhesion. Inter laminar shear strength (ILSS) of composites has been improved by ultrasonic. The microscopic properties of resultant composite examine by these methods as XPS and AFM. The ILSS is attributed to the ultrasonic cavitation, which improves the wetting between aramid fibers and resins.

Zhang et al.[12] Has performed experimental investigation on ultrasound used to quantify deformation damage in polyethylene plate. Specimens thickness in the range from 1.5 to 10 mm. firstly specimen stretched monotonically to various pre-strain level to vary extent of damage introduced by streach. The result shows the ultrasonic velocity, normalized by the speed in the vestal plate of the same thickness, decreases with the increase in pre-strain. The correction of density change by the pre-strain, normalized ultrasonic velocity can be used to determine the damage level on the pre-strain.

Fitzka et al. [13] Has performed experimental investigation on ultrasonic fatigue testing of MP35N thin wires. Fatigue testing of thin wire is time consuming by conventional methods. A complete characterization of material's fatigue properties however requires many specimen. First time thin wire with the ultrasonic fatigue testing, the wire stressed with the cyclic tension loads. Results of fatigue tests at a cyclic frequency of around 20kHz up to lifetime of 10^9 cycles at load ratio 0.3 are shown

Costa et al. [14] has performed experimental investigation ultrasonic test is performed to find grain distortion. Using a digital oscilloscope and thickness of material is known by this ultrasonic velocity is determined. Test shows the difference in wave velocity for different orientation of grain structure. The measurement result were statistically analyzed and graphically presented. The results are verified by homogenous testing method. This work leads to a non-destructive, simplified way of anisotropy recognition without more expensive destructive testing.

Adamus et al. [15] Has performed experimental investigation to evaluate the feasibility of walled component (aluminum) by ultrasonic waves. Aluminum alloy used in varies industry and aluminum lithium alloys used to reduction in weight by 10-20%. Technology developed for testing of thin walled component made of aluminum based sheet by ultrasonic testing of aluminum laminated having section thickness of 1.5mm is presented. Ultrasonic method detected discontinuities of 0.4mm width or grater then that.

Mesa et al. [16] Has performed experimental investigation by ultrasonic vibration assisted ball burnishing (VABB) tool on Ti-6Al-4V for design and characterization. Conventional ball burnishing by means of addition of a 40Kz vibratory force to the burnishing. VABB technique is feasible means of characterizing this sort of advanced manufacturing tools especially which governed by ultrasonic frequencies. VABB tools as inexpensive systems to successfully execute an innovative process for industry component

3.0 CONCLUSION

The major objective of this work was to develop a reliable method for non-destructive evaluation of boiler tubes, where then subjected to nondestructive and destructive tests. It was concluded that the major damage mechanisms were either wall thinning or overheating damage and a combination of both. Two ultrasonic test procedures were recommended for early detection of both these damage types without necessity of removing tube from the boiler. EMAT has been proven as an effective method for quick and accurate wall thickness measurement in water-wall boiler tubes without prior cleaning. This study had demonstrated that correlation exists between the scale thickness and degree of creep degradation for boiler tubes. The procedure was recommended for determining tube remaining life under combined effect of thinning and overheating. Future work is needed to obtain a full quantitative correlation for creep damage vs. internal oxide thickness for low carbon steel. NDT methods offer an attractive solution to remaining life assessment in power boilers due to their ability to accurately determine remaining wall thickness and hoop stress in tube and to indirectly detect the degree of creep damage by measurement of internal oxide thickness.

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