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REVIEW ARTICLE

Applications of Ultrasonic Testing (UT) for Irregularities Detection in Human Body and Materials: A Literature Review

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ABSTRACT

Ultrasonic testing (UT) for medical examination as well as metal flaw detection is a popular method. From the beginning of ultrasonic testing conducted by Mulhauser in 1931, a lot of new things and technologies emerged in UT testing. This review paper deals with progress in detecting human organs as well as materials flaws and future prospects of UT for metal flaw detection. Study on components of UT system is conducted. Then typical UT inspection system is determined. After that advantages and disadvantages of UT have been reviewed. Major types of waves in ultrasound with considering UT instruments have been reviewed as well. Progress in different areas of UT have been discussed extensively with more emphasis on progress in composite piezoelectric materials, variations of probes, EMAT (Electromagnetic Acoustic Transducer), focused probe, focusing axicon probe, focused phased arrays, LASER (Light Amplification by Stimulated Emission of Radiation) generation of ultrasound, acoustic holography, and ultrasonic microscopy. At the end future prospects of UT have been reviewed as well as recommendations have been provided.

KEYWORDS: *Ultrasonic wave, NDT, NDE, Couplant, EMAT*

INTRODUCTION

Ultrasonic technology is a NDT (Non Destructive Testing) method that uses high frequency sound energy [1]. These high energy sound waves transmit into human organs as well as the material, and reflected echoes are collected and analyzed by Ultrasonic Testing (UT) machine for metal flaw detection. This testing method is also used for medical diagnosis, dimensional measurements, materials characterization purposes etc. Due to complexities involved [2-7] in UT system it is very important to study UT system in details. Very few literatures are available currently to fully describe the UT system where its prospects are and how to improve the system. In this review work detail analysis has been conducted on UT system with prospects and improvement plans have been analyzed.

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Components and Working Principle of UT System:

Typical UT inspection system contains: pulser, transducer, and display devices. At first pulser produces high voltage electrical pulses and send these signals to transducer. Eventually, high frequency ultrasonic energy is generated by transducer. This ultrasonic energy passes through human body as well as metals as waves and if any organ (e.g. stone etc.) or flaw is present will be echoed from surface of the flaw and will be reflected back to surface of the metal. The reflected wave signal is again converted into an electrical signal by the transducer and is displayed on a screen. Signal travel time can be directly converted to the distance (that the signal traveled) and eventually position, size and orientation of the flaws can be detected.

Typical UT Inspection System:

Typical UT inspection system is shown in Figure-1. Figure shows immersion type UT system widely used in engineering laboratories for flaw detection. Where water works as medium of sound wave and a motion stage is controlled by controlling system.

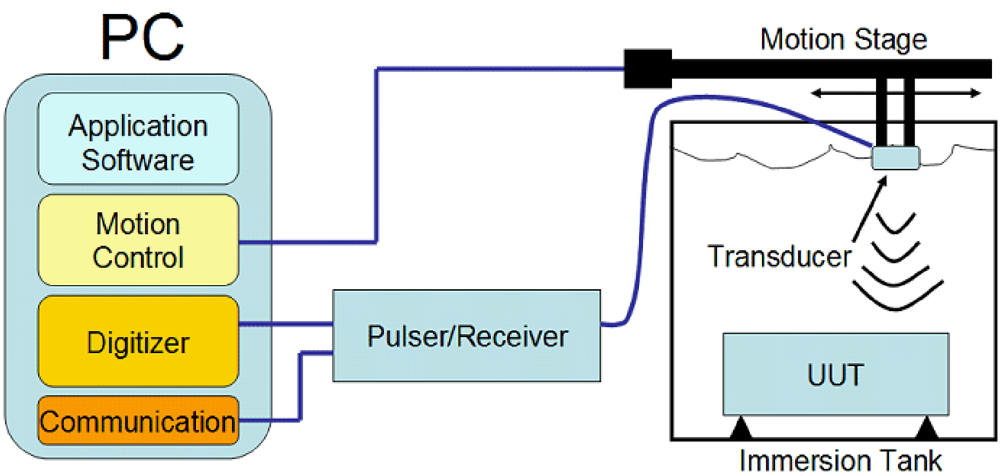

Fig 1. Typical UT inspection system [2]

Position of flaw (defect) can be detected by the simple equation:

$$d = \frac{vt}{2}$$

where, $d =$ distance from probe to target spot/crack, $v =$ velocity, and $t =$ time

Advantages of UT:

Several of advantages of UT system lead it to metal flaw detection. Especially, depth of penetration for flaw detection is higher than other non-destructive method (NDT) methods. This method is also sensitive to both surface and subsurface discontinuities. It has a major advantage of highly accurate in determining size and shape. Using automated system detailed images can be produced by UT.

Disadvantages of UT:

In addition to its advantages, there have some disadvantages of UT system as well. To transmit ultrasound the surface must be accessible to UT system. For this purpose coupling medium is required. Materials which are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect by this system. Also materials like cast iron and other coarse grained materials are difficult to inspect. Defects oriented parallel to the sound beam may go undetected by this system as well. However, reference standards are required for equipment calibration and characterization of flaws and skill and training is more extensive than other NDT methods. Research work is going on to minimize these disadvantages and trying to come up new solutions to handle these problems.

Major Types of Waves in Ultrasound:

UT testing is based on time varying vibrations/deformations of metal by sound waves. Typical of waves in acoustics or sounds are: longitudinal waves, shear waves, surface waves, and plate waves (in thin materials). In longitudinal wave oscillation occurs in the direction of wave propagation. In shear wave oscillation occurs in perpendicular direction of wave propagation. In this work major types of waves in UT: Longitudinal wave and Shear wave have been considered. Figure-2 shows these two major waves in materials and how particle vibrates.

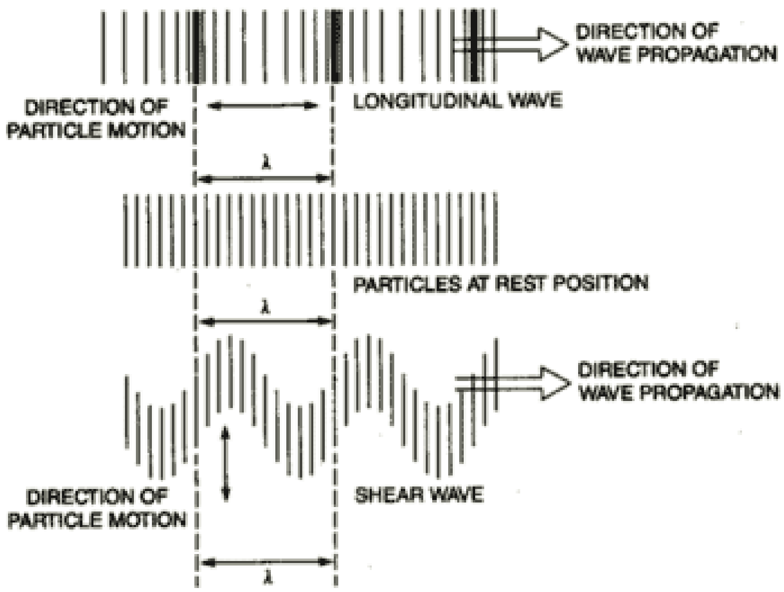

Fig 2. Longitudinal and shear waves [1]

UT Instruments:

UT instruments are portable devices and easy to use. Figure-3 shows an Ultrasonic test monitor. Couplant is used in UT system. Contact type UT is widely used in medical purposes and water couplant type UT is used in engineering laboratories for testing metal flaws. Figure-4 shows contact and water couplant type UT system.

Fig 3. Ultrasonic test monitor

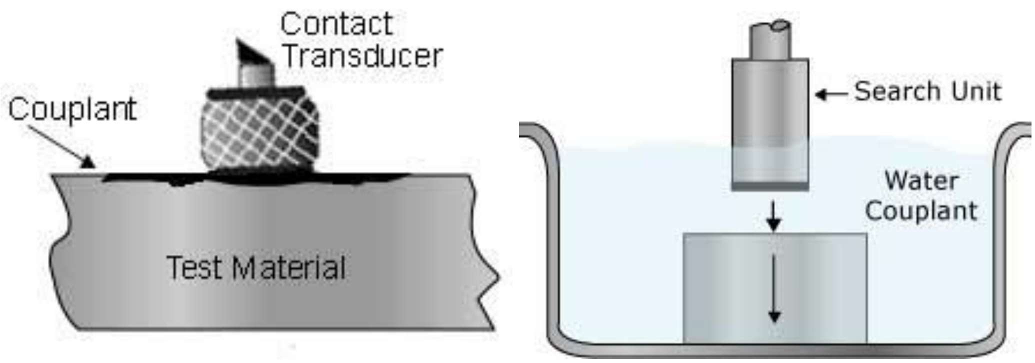

Fig 4. Contact test using couplant and water couplant Ultrasonic test [3]

Progress in Different Areas of UT:

There had been some progresses in ultrasonic testing. Most of the progresses are to minimize the disadvantages of UT systems, like the area of generating ultrasonic waves in different ways, using many transducers than just one transducer to enhance ultrasonic energy etc. In this review work progress in ultrasonic testing are arranged as: composite piezoelectric materials, variations of probes, EMAT (Electromagnetic Acoustic Transducer) for non couplant, focused probe, focusing axicon probe, focused phased arrays, LASER generation of ultrasound, acoustic holography for data recording and ultrasonic microscopy for sample examination.

Progress in Composite Piezoelectric Materials:

One of the advantages of using composite piezoelectric material for UT system is it provides higher sensitivity than single material. Composite piezoelectric in UT system is shown in Figure-5. Different grades of lead zirconate titanate (LZT) are widely used piezoelectric material for UT system. Another recently used piezoelectric material is lead metaniobate and polyvinylidene fluoride (PVDF). The later can be shaped in virtually any way which leads to some progress in UT system. Although it is very hard to manufacture composite piezoelectric materials, however several of industries have got success in manufacturing composite piezoelectric plates [4-10] especially Krautkrämer [7]. Gaps between the elements are filled with epoxy resin compound.

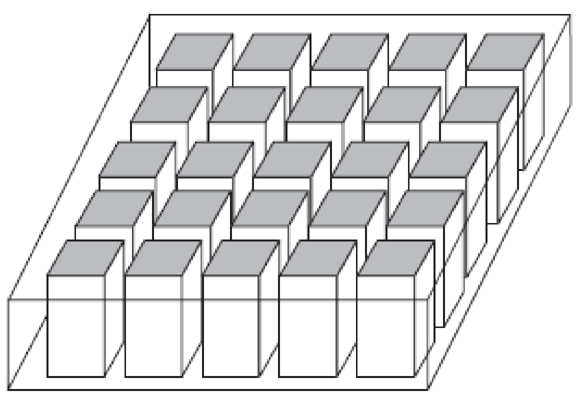

Fig 5. Composites piezoelectric transducer [1]

Progress in Variations of Probes:

Recent progresses in UT are also in the areas of variations in number of point of contact and the way of contact of the UT system probe with the surface [11]. The advantages of contacting more than one part/region at a time will lead to more accurate detection of metal flaws. Single and twin contact piezoelectric probes are useful to detect de-bonds in hard metals, metal honeycomb and multi layer composites. However, tapping probes are useful to detect de-bonds and voids in soft materials such as rubber, polymer and plastic based structures. Figure-6 shows single and double contact piezoelectric probes contacting with metal surfaces. Also this figure shows tapping with microphone and piezoelectric receiver another progress in UT system.

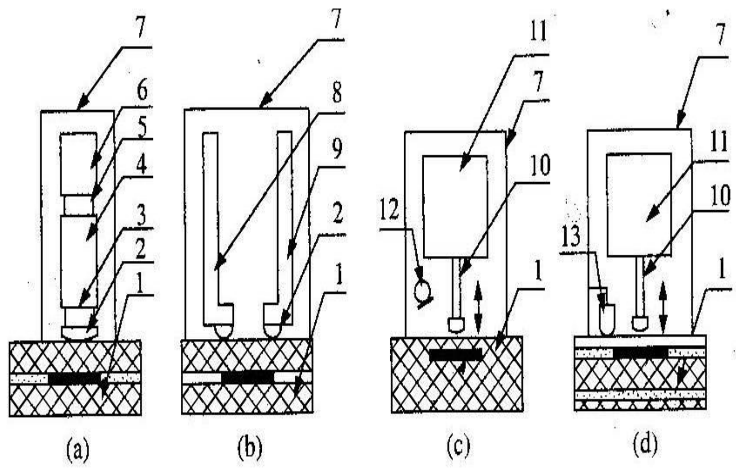

Fig 6. (a) Single contact Piezoelectric (b) Twin contact piezoelectric (c) Tapping with microphone receiver (d) Tapping with piezoelectric receiver [11]

Progress in EMAT (Electromagnetic Acoustic Transducer):

EMAT is a different way of generation of sound [12-16]. Eddy-currents generates when presence of external magnetic field place near conductive specimen (pancake coil) that eventually produces mechanical force and leads to mechanical vibrations and generates ultrasonic wave in material. This can be shown as a flow chart:

Electrical Energy → Mechanical → Vibration Ultrasonic wave

This can be observed in Figure-7. Longitudinal wave generated by EMAT is depicted in Figure-8. Magnetic field parallel to specimen surface produces vibrations to metal particle and oscillation move in the direction of wave motion. However, in shear wave generated by magnetic field perpendicular to specimen surface, create perpendicular oscillation to particle with the direction of wave motion as shown in Figure-9.

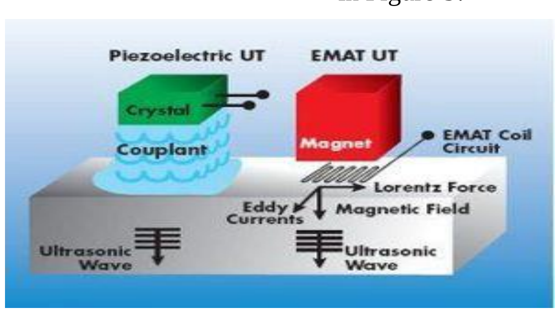

Fig 7. EMAT in UT system [13]

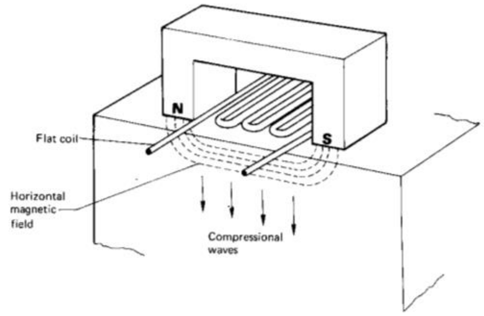

Fig 8. Longitudinal wave generated by EMAT [12]

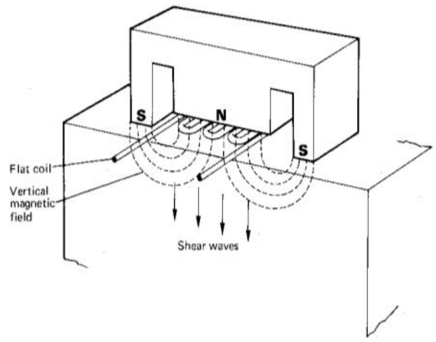

Fig 9. Shear wave generated by EMAT [12]

Advantages of EMAT:

Several of advantages of EMAT made it more useful: dry inspection is possible, no couplant is required, minimum sensitivity to surface roughness and specimen preparation is not necessary.

Progress in Focused Probe:

Technical advantages in modifying the ultrasonic beam shape by focusing the beam to a narrower cross section by making curved plate of piezoelectric material [17-20]. For this type of lens design, underlying principle is exactly the same as for an optical system lens. Typically used acoustic lens are: perspex or polystyrene as shown in Figure-10.

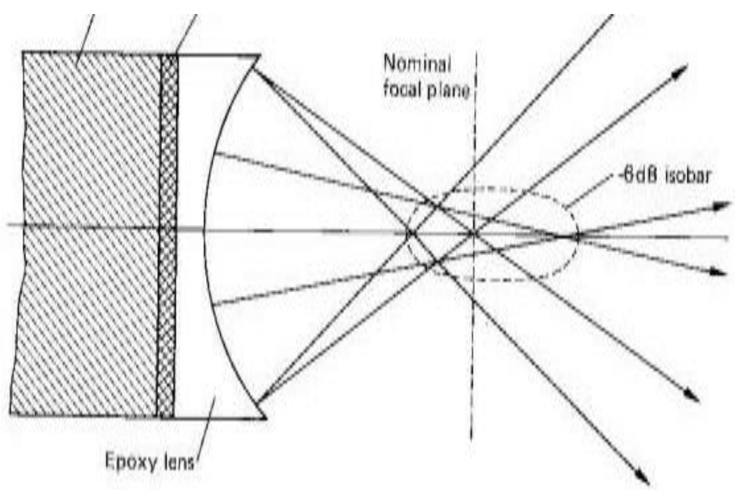

Fig 10. Focused probe [12]

Progress in Focusing Axicon Probe:

Technical advantages are also to create an acoustic field in which power is concentrated near the axis in a possibly wide distance range [17-20]. The best results from this is obtained, using an axicon send/receive probe. It contains two piezoelectric elements, namely, a plane plate in the center and a focusing ring around it as shown in Figure-11.

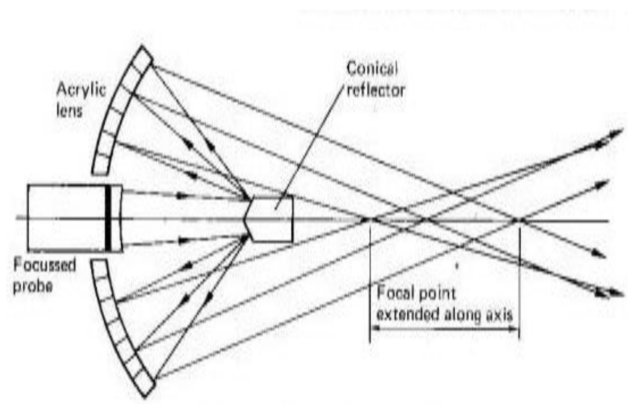

Fig 11. Focusing axicon probe [12]

Progress in Focused Phased Arrays:

Recent UT inspection system is also using array of transducer [17-20] elements as shown in Figure-12. If the phase or time delay to each element is remained controlled, shape and direction of ultrasonic beam can both be modified. Typical array might consist of one-hundred 10x0.3 mm silvered PZT strips cemented to a backing block to oscillate at frequency of 4 MHz. However, constructional problems prevented probe arrays being widely used in industrial applications.

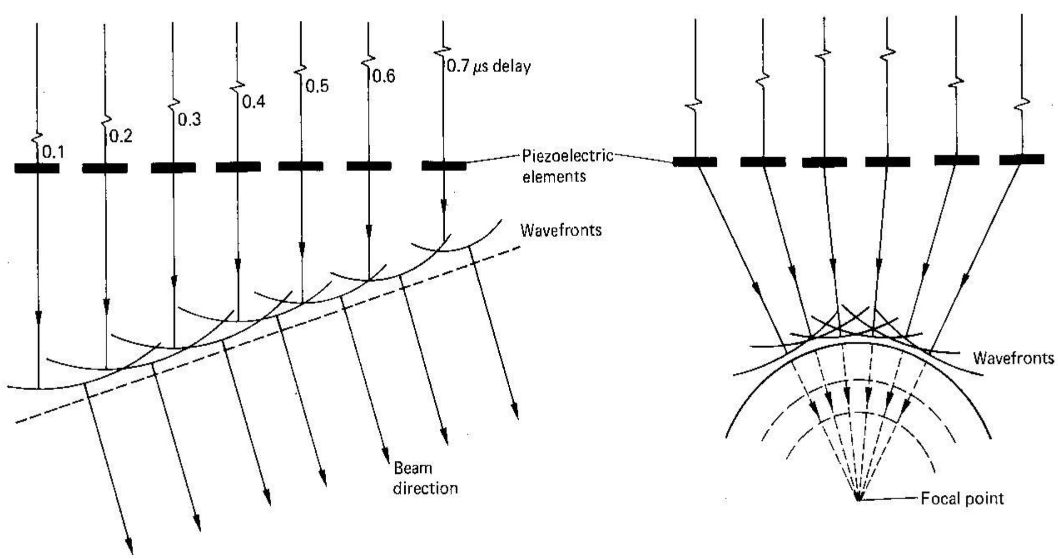

Fig 12. Focused phased array [12]

Progress in LASER Generation of Ultrasound:

Progress in UT system also is made in different ways of generation of ultrasonic wave by LASER [22-26]. LASER is shortly called from Light Amplification by Stimulated Emission of Radiation. Figure-13 shows a LASER gun producing LASER with different components in it and figure-14 shows engineers working with LASER in a lab.

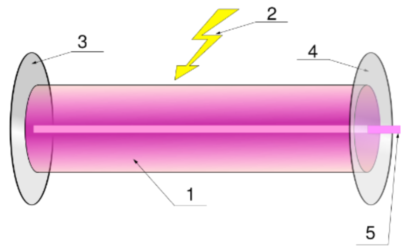

Fig 13. LASER system consisting of (1) Active laser medium, (2) Laser Pumping energy, (3) High Reflector, (4) Output coupler, (5) Laser beam [21]

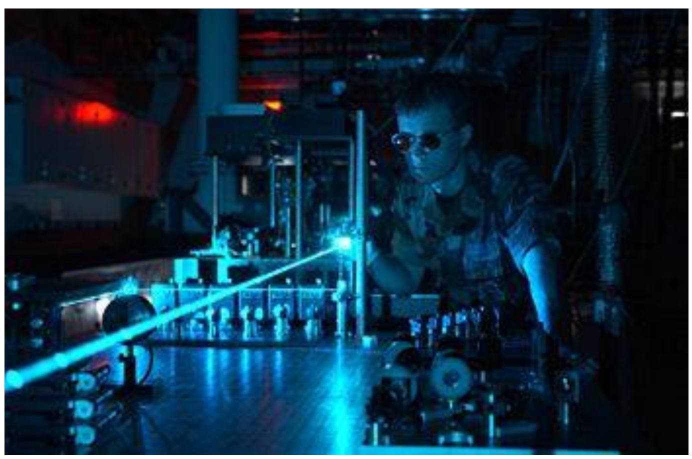

Fig 13. Testing with LASER beam [27]

During generation of LASER beam electron is pumped to a higher energy level in LASER gun. As pumping is unstable, so the electron quickly jumps to a slightly lower energy level to get a stable state. However, during that time electron relaxes to a lower energy state and releases a photon which is a beam called as LASER as shown in Figure-15.

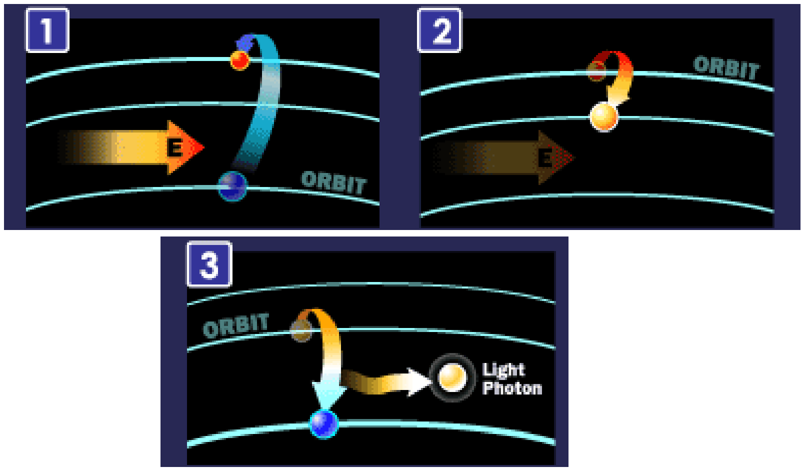

Fig 15. Steps in making LASER beam [27]

Laser beam impinging on solids produce very high energy absorption and eventually will lead to rapid thermal expansion in materials. Very rapid thermal expansion results in generation of ultrasonic pulses in materials. These acoustic fields were visualized by using a laser interferometer in order to observe the displacement of points on a surface by ultrasonic wave propagation. Compression (Longitudinal) and Shear waves and other kinds of waves can be generated by using LASER. Pico-second laser pulse will generate about 2 ns long ultrasonic pulse and can be used for extremely thin specimens.

Progress in Acoustic Holography for Data Recording:

Progress in UT system is also in the area of recording data to visualize the metal flaw accurately [8]. Data recording data can be done by the concept of optical holography method. Optical holography is a 3D data on a 2D recording surface. It is also a form of photography where an image (hologram) which conveys a sense of depth. It also optically stores, retrieves, and processes information. Figure-16 shows a hologram of an ID card.

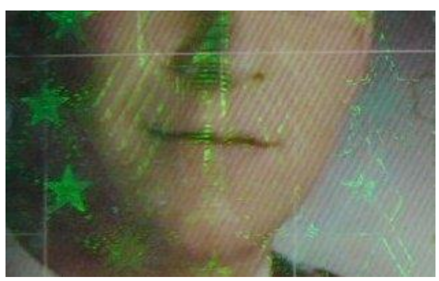

Fig 16. Hologram of an ID card [27]

Like photographs, holograms records reflected light. Figure-17 shows how holograms can be made to store data. In holographic device shutter opens or moves out path of a LASER. Light is split by beam splitter and made object beam and reference beam. The object beam passes through diverging lens and falls on mirrors. Eventually it reflects on the mirror and comes to the object. The light from the reference beam bypasses the object entirely. The light from both beams comes into contact with photographic emulsion, where light-sensitive compounds react and hologram is made.

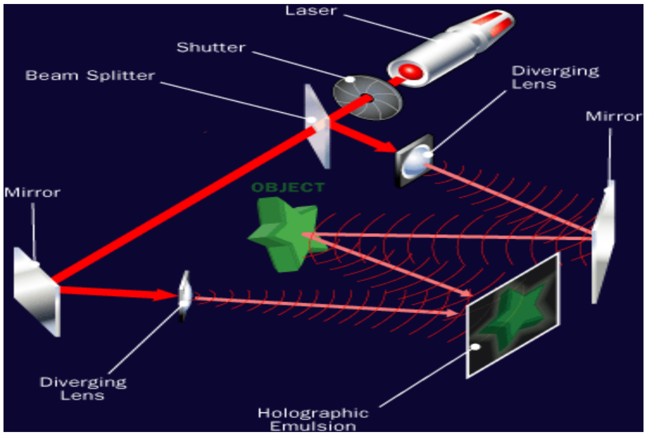

Fig 17. Holographic recording process [27-28]

As, ultrasonic pulse is a coherent radiation so similar technique can be applied for UT inspection. Recording is carried out along a line (linear holography) and the image is recovered in a single plane (layer). This technique is still in research stage.

Progress in Ultrasonic Microscopy for Thin Sample Examination:

Ultrasonic microscopy is an automated or mechanical microscopic examination of small/thin objects [7-8]. This allows a resolution of hundredths of a millimeter. By this technique set of results are processed to obtain an acoustic image of internal volume or cross section of article being tested. Scanning is performed by an automatic mechanical device using a step of 0.1–0.2 mm. The probe position is electrically connected with a data processing system. Avgur system developed at Scientific and Production Center Echo+ is an example of such an instrument. This technique is similar like optical microscopy as shown in Figure-18.

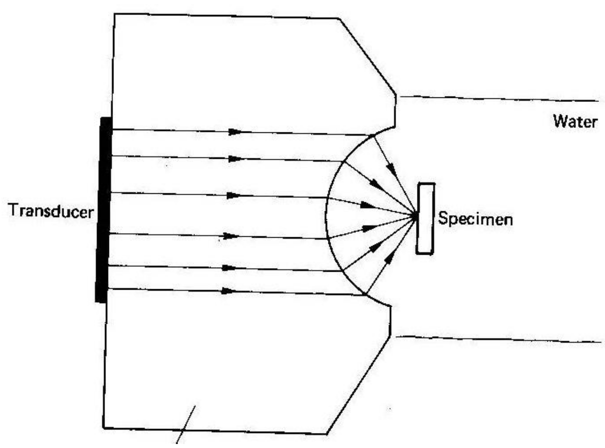

Fig 18. Acoustic microscope [12]

Few Other Aspects:

As surrounding media is air or liquid (gel/couplant), therefore liquid and gas absorption and dispersion of Ultrasonic sounds during testing is discussed in different literatures [29-32]. This will help identify the leak related with Ultrasonic testing and how to have efficient detection with less energy consumption.

Materials aspects for anisotropic and isotropic materials also need to look at during Ultrasonic testing. A lot of literatures devoted to this kind of study [33-36] where transmission of Ultrasonic waves dependence of materials properties are observed. This kind of study will help to use right amount of Ultrasonic waves (corresponding to less energy use) for different materials.

While radiation aspect is primarily needed during Ultrasonic testing, however irradiation aspect also needs to look at. A lot of literatures addressed [37-40] irradiation aspect of Ultrasonic wave which can be used for different purposes of metal and biological important applications.

While steady state situations are mostly observed and used in Ultrasonic testing, however transient (time sensitive and varying) aspects are also growing in use. A lot of literatures [38-45] dealt with transient aspects and use of Ultrasonic testing. These indicate wide variety of use and applications of Ultrasonic beams.

CONCLUSION:

Review has been conducted on progress in UT for detecting medical diagnosis, human organs as well as materials flaws and future prospects for metal flaw detection. At first study on components of UT system with typical UT inspection system is determined. Major types of waves in ultrasound with considering UT instruments have been reviewed as well. Progress in different areas of UT have been discussed extensively with more emphasis has been given on progress in composite piezoelectric materials, variations of probes, EMAT (Electromagnetic Acoustic Transducer), focused probe, focusing axicon probe, focused phased arrays, LASER generation of ultrasound, acoustic holography for data recording and ultrasonic microscopy for thin sample examination. It is expected that this review and study will enhance understanding of complex UT system.

Future Prospects of UT:

Although there have been significant progress in Ultrasonic Testing in recent years, however lot of areas in UT as NDT and Non Destructive Evaluation (NDE) methods need to be developed. Future promising direction for the development of ultrasonic testing involves combining computer acoustic holography with LASER transmission and reception of ultrasonic pulses [7-8]. This will improve capability of testing coarse grain materials, and visually display testing result. Broad-band pulses emitted by LASER will make it possible to use multi-frequency holography. In the future rather than scanning performed manually or by a complex mechanical device, it can be carried out by an optoelectronic laser-deflection system which can be connected with an imaging system to display the image.

Advanced computer simulation tools will contribute to increase number and types of engineering applications of UT [46-55]. Figure-19 shows computer simulation work for UT system. As UT involves training and skill to interpret the data so more advancement in computer simulation tools will lead to help training facility and save money before going for UT experiments for flaw detection.

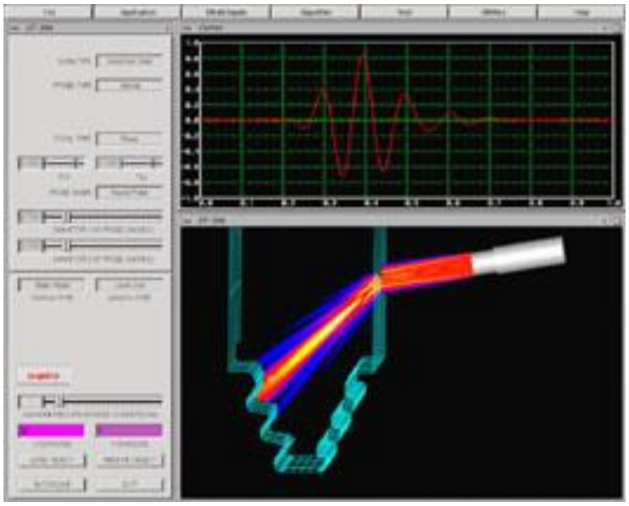

Fig 19. Computer simulation of Ultrasonic testing [46]

Instrumentations and testing procedure might look different in the future for Ultrasonic testing [7-8]. Presently an inspector manually scans an article's surface greased with oil, simultaneously observes the signals on a display, and then interprets the results. However, there can be a LASER transmitter–receiver installed near to the surface. After scanning the surface with a beam, the instrument can demonstrate an image of the flaws on a display device and simultaneously evaluate their parameters digitally. In that way more information can be found from UT system once data can be taken.

ACKNOWLEDGEMENT

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