FLAW DETECTION USING ULTRASONIC TECHNIQUES

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING
(With Specialization in Measurement and Instrumentation)

By

RADHEY SHYAM ANAND

DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE-247667 (INDIA)

JULY, 1987

DEDICATED

TO

VEE JEE

CANDIDATE'S DECLARATION

I, hereby, certify that the work, being presented in the thesis entitled, 'FLAW DETECTION USING ULTRASONIC TECHNIQUES', in partial fulfilment of the requirement for the award of the degree of MASTER OF ENGINEERING with specialisation in MEASUREMENT AND INSTRUMENTATION and submitted in the Department of Electrical Engineering, University of Roorkee, Roorkee, is an authentic record of my own work carried out for a period from July 1986 to June 1987 under the supervision of Dr. H.K.Verma, Professor, Department of Electrical Engineering and Dr. Vinod Kumar, Reader, Department of Electrical Engineering, University of Roorkee, Roorkee.

The matter presented in this dissertation has not been submitted by me for the award of any other degree or diploma.

Dated July 16, 1987

Radhey Shyam

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

16/7/87
(Dr. H.K.Verma)
Professor
Department of Electrical Engg.
University of Roorkee,
Roorkee, India

16/7/87
(Dr. Vinod Kumar)
Reader
Department of Electrical Engg.
University of Roorkee
Roorkee, India.

ACKNOWLEDGEMENT

It is a great pleasure to me to express a deep sense of gratitude to my beloved guides, Dr. H.K.Verma, Professor, Department of Electrical Engineering, University of Roorkee, Roorkee, and Dr. Vinod Kumar, Reader Department of Electrical Engineering, University of Roorkee, Roorkee, whose invaluable guidance and constant encouragement inspired me to accomplish the dissertation work, so successfully.

It would not be out of place to express my heart felt thanks to my friends, Subhash Verma, Sushil Kumar, Kailash Rathore and Amarnath Mishra, whose precious assistance and suggestions in every crucial field of my life, made me capable to overcome the difficulties coming in the process of dissertation work.

Finally, I wish to express my thanks to all the technicians of Electrical Engineering Department, who directly or indirectly rendered their help.

Radhey Shyam

ABSTRACT

Testing of materials by sound note is one of the oldest applications of sound for detecting the hidden defects. It is a non-destructive testing method unlike a destructive mechanical method, where the testing of specimen crack is performed by stressing it by tension or bending until the crack manifests itself by an open-break. The transition from audible sound to ultrasonic sound (nowadays, widely used for flaw detection) has become possible by its modern methods of generation and detection.

In modern days, the non-destructive testing (NDT) also known as non-destructive evaluation (NDE), has become the basic inspection tool of industries. The product development, process control, flaw detection, quality evaluation and measurement of mechanical and physical properties are the most reknowned fields where the NDT methods are widely employed.

In this dissertation, the whole work is carried out for detecting the flaws in a material by using ultrasonic techniques based on pulse-echo method. The entire discussion accounts for the working principles, design aspects and important features of the two systems developed by the author. An effort has also been made to produce a brief review of various other ultrasonic flaw-detection techniques.

The entire testing has been performed on bars of brass material. The related data so obtained is therefore, applicable only to this particular material.

The first system designed and implemented is the A-scan with digital readout. It gives the measure of the exact location of the flow on a digital display unit. It uses a single transducer assembly, which acts first as an emitter of ultrasonic pulses and then as receiver to detect echoes from defects or other interfaces. Transmitter circuit provides the required signal to excite the transducer while the receiver circuit consisting of rf amplifier, video amplifier and demodulation and suppression circuit performs the analog processing of the signal received by the probe. The exact formulation of transit time (i.e. interval between transmitted and first return echo) of first return echo into a interval pulse is achieved through a digital processing unit which comprises of logic inverters, AND and EX-OR gates. Finally, the digital display unit shows the exact measure of flaw location in numerical values.

The system so developed is capable to detect the flaws located at 30 cm or more from the transducer face. The maximum limit goes upto 2.5 meters. The low damping of the transducer, employed here, affects its resolution to a great extent. This puts a limitation to the present system in form of its incapability to detect the flaws within the range of 30 cm from the transducer face and also, its insensitiveness to distinguish the flaw in the span of 30 cm.

The second system is an ultrasonic imaging system which produces a cross sectional image of the test piece on CRO towards its front face (i.e. scanning face). The process of transmitting and receiving the ultrasound in the system is also the same as for the previous system discussed earlier. The difference lies only in the clock signal which here is generated by the microprocessor rather than by a 555 timer. The transit time measurement is performed by the µp itself. The scanning mechanism comprised of two stepper motors is the additional unit providing the linear and step movement to the transducer. The microprocessor (i.e. CPU) here performs the functions of generating and receiving position signals, storage of these position signals and transit time information along with the clock generation to excite the transducer at a particular frequency known as pulse repetition frequency. The outputting of the stored position signals (x and y coordinates) along with the transit time (z-coordinate, fed to the z-modulation point of the CRO) in succession, produces an image in form of a dot matrix giving the information about the flaw shape and its relative location. The brighter spots represent the flaws of nearer locations. Resolution in the present system is also affected by the low damping of the probe.

The present system presents a great deal information about the flaws located within the span of 20 cm to 70 cm from the transducer face. The lower limit, mainly determined by transducer damping, can be reduced if a high damping transducer is used. The upper limit in this case is much enough for any specimen to be scanned.

In the end some suggestions for future work are also given.

CONTENTS

contd...

CHAPTER- 3 REALTIME ULTRASONIC IMAGING SYSTEMS (PART-I)

CHAPTER-4 REALTIME ULTRASONIC IMAGING SYSTEMS (PART-II)

CHAPTER-5 DEVELOPED ULTRASONIC IMAGING SYSTEM

CHAPTER - 1

INTRODUCTION

1.1 WHAT IS ULTRASONICS.

The science of sound, named Acoustics, describes the phenomenon of mechanical vibrations and their propagation in all the three types of materials, solid, liquid and gas.

In the same way, as the light waves over visible frequency range are called ultravoilet, the sound waves above 20 KHz (i.e. beyond human hearing range) are referred as ultrasound or ultrasonics. The sound waves below 10 Hz are suggested to be called as subsonics. In ultrasonics there are many other frequency boundaries e.g. infrasonics, supersonics, hypersonics, macrosonics etc. In all, division of sound waves is purely arbitrary and is based on the human hearing range.

1.2 A BRIEF HISTORY OF ULTRASONICS.

In 1808, Jean- Baptise Biot of France gave the first recorded experiment with the propagation of sound in solids [1]. But the propagation of ultrasonic waves is in the credit of Paul Langevin who in 1917 transmitted sound waves in sea water [2]. He has been, so,called the father of ultrasonics. His theoretical and experimental work was based on background provided by earlier investigators. The exact formula for the velocity of sound in air and water was introduced by Pierre Simon Laplace. while for sound velocity in solids, the Poisson was the keyman who showed it for isotropic solids. Likely, the surface waves were described by Lord Rayleigh in 1887. Pierre and Jacques Curie discovered the piezoelectric effect in 1880. The piezoelectric effect is one of the phenomena which produce the ultrasonic waves. In a similar way, the other effect for producing waves in materials, the magnetostrictive effect, was discovered by J.P. Joule in early half of nineteenth century.

The first application of these effects was production of sound waves in water. for the detection of submarines [2] For many years, it was the only application. This work was started in World War I due to the great loss of shipping resulting from German submarines.

During World War II, piezoelectric crystals of ammonium dihydrogen phosphate (ADP) were found to be more suitable than rochelle salt. Since World War II considerable work has been done to improve submarine detection and destruction.

R.W.Wood and A.L.Loomis showed interest in the effects of high- intensity sound. They established techniques for generating high acoustic powers and started measurement of relevant properties. Many striking effects, which can be produced by high intensity sound, were also shown. But the most of them were mainly demonstrated in laboratories.

The first practical application of ultrasound other than the underwater sound, was the ultrasonic flaw detection system for locating flaws in materials. This was firstly introduced by S.J.Sokolov of USSR in 1929. The same work was also performed by A. Frost, O. Mulhauser and R.Pohlman in Germany during 1930s. Between 1939 and 1945 America and Brittain also worked in the same field independently. However, the invention of ultrasonic 'reflectoscope' by Floyd A.Firestone in 1940 led to the development of modern ultrasonic non-destructive testing (NDT) equipment. This system is also called the forerunner of modern pulse-echo equipment. In this respect, it competes with X-ray and other inspection methods.

In the low-amplitude category, besides the increased activity in underwater sound, ultrasonic vibrations were applied as an adjunct to Radar. It was during World War II that liquid and solid delay lines[2] were developed for use in timing devices, antijamming devices and moving target indicator radar systems.

Upto 1945, the principal transducer materials were quartz crystals, ADP crystals and magnetostrictive materials. In 1945, a big advance was achieved by the use of ferroelectrics (materials with natural polarization) that can be obtained in ceramic form. The first of these ferroelectrics barium titanate ($BaTiO_3$) was discovered independently by Von Hippel and associates of MIT and by Vul and Goldman USSR.

At the end of World War II, one important investigation, limiting frequency (10^{13}Hz) associated with lattice dynamics, was made. This proved to be beyond the ability of present day ultrasonic transducers which are limited in frequency to 100 GHz (10^{11}Hz).

Since 1945, there has been continuous and steady increase in the amount of research work done in ultrasonics specially, in industrial processing applications and non-destructive methods.

1.3 APPLICATIONS OF ULTRASONICS.

The science of producing and transmitting sound waves in materials, has now become a fluorishing art with many practical applications.

The low-amplitude application includes under water sound transmission for locating submarines, measuring the depth and detail of ocean bottoms, flow detection in materials, delay lines for storing information and for performing many processing calculations and many medical applications, such as, locating cancers and other imperfections in human body. Ultrasonic waves are also being used in many physical investigations.

The sound waves of large magninude generate non-linear effects, such as, the production of cavities in liquids and fatigue in solids. This gives rise to another series of applications, viz. ultrasonic cleaning, emulsification of liquids, machining of materials and tests for fatigue in materials particularly, when a large number of cycles is required. In biomedical applications, the destruction of bacteria and the use of focussed ultrasound as a surgical knife are also possible.

1.4 NON-DESTRUCTIVE TECHNIQUES

The non-destructive evaluation (NDE) employes the techniques that check the compliance of materials, quality and its structural integrity to agreed specifications without in any way affecting the service ability of the objects so tested.

At present, industries are applying and studying over more than two dozen non-destructive evaluation methods. Nearly, all of them have appeared since 1920s and most since 1940s. Five NDE methods, however, used industrially for more than any others, are radiography, ultrasonics, eddy current, magnetic particle and fluorescent liquid penestrant. Workers in the field popularly refer to this group as the Big Five [3].

1.4.1 RADIOGRAPHY.

Wilhelm Rontgen discovered X-rays in the early start of 20th century. Implementing the Pioneer work of Horace H. Lester and U.S.Army Watertown Arsenal in Massachusetts, radiography became the first method of internal visualisation, to be adopted to NDE by early 1930s. During World War II, millions of radiographs were taken to search for defects in a large variety of military rated components. Like the familiar X-ray in medical field, this method works as a sandwich to the components between a source of highly penetrating radiation and a piece of photographic film to make a film record of the internal condition of the object.

Three types of radiations are used in industrial radiography; X-rays, gamma rays and neutrons. The X-rays and gamma rays are the electromagnetic waves like radio waves or visible light but comparatively, they have much higher energy. X-rays are the radiations coming from the lost kinetic energy of the rapidly decelerated electrons and are produced as a result of collision of high-speed electrons with a metal target.Gamma rays are emitted as a natural phenomenon from the nuclei of decaying radioactive isotopes such as cobalt-60. Electrically uncharged neutrons, on the other hand are ejected during nuclear fission or nuclear reactions induced by atomic particles striking a suitable target.The object under examination penetrated by beam of radiation reduces or attenuates the intensity of the beam in proportion to the thickness being penetrated and its capacity to the form of radiation. Voids, changes in thickness or regions of differing material composition will produce projected shadows and highlights of themselves on film.

1.4.2 ULTRASONICS

A high rank exists in the credit of ultrasonics on the list of NDE methods. Like radiography, it is capable of detecting defects hidden in the interior of a part. Ultrasonics, however, is more sensitive to minute flaws than radiography. It can be used to inspect the material from one side also producing the comparable results when inspected from both sides. In the method, the high frequency sound waves (at millions of cycles per second) are launched into the material, being inspected. The inspection is carried out either by detecting echoes from a discontinuity, such as, crack or a foreign substance coming in the way of waves (pulse-echo mode) or measuring the reduction in signal strength as the attenuated wave exits the material (through transmission mode).

Virtually, in all procedures, ultrasonic wave is launched and received with piezoelectric transducers made of such materials as lead zirconate titanate. When an oscillating electric field is applied to these crystals, they vibrate mechanically at high frequency. Contersely, an oscillating current is produced when they are forced to vibrate mechanically. The component under test is coupled by a thin grease film or a water path. The vibrating crystal induces the elastic waves of the same frequency (the natural frequency of the crystal) which propagate into the material under test. Either compressional or shear waves (vibration along or perpendicular to the direction of propagation) can be produced. Compressional waves have higher sensitivity to some defects as compared to shear waves.

1.4.3 EDDY CURRENT METHOD

The analytical and experimental work about eddy currents was introduced by German scientist Friedrich Forster in 1940. This provided most of the early scientific method to investigate the eddy current method of testing. The best utilisation of eddy current method is to locate surface flaws or near surface flaws in electrically conductive materials. To a lesser extent, it is used in evaluating material properties like hardness and in sorting the types of alloys. The methods exploits the secondary current (eddy current). These are induced electromagnetically within the surface region of a conductive material under test, when a wire coil itself excited by an alternating current is positioned close to the test piece. When the coil probe passes over a crack in the test piece, the eddy currents are distorted producing a measurable signal in the electronic circuit (monitoring the coil). Since the frequency substantially determines flaw detectability, the frequency of the field generated by the coil is a very important factor is eddy current test.

Deeper field penetration is provided by lower frequencies but small surface flaws now face reduced sensitivity. On the other hand,higher frequencies increase surface flaw sensitivity while becoming almost insensitive to subsurface flaws. The factors such as coil design, electronic instrumentation, test procedures, signal analysis and the skill of the inspector also influence the eddy current inspection method.

1.4.4 MAGNETIC PARTICLE INSPECTION.

This type of NDE method is based on the way surface cracks disturb the magnetic fields in ferromagnetic (strongly magnitisable) materials. Applied mainly in testing of iron and steels, they came to existence in the late 1920s. Elmer A. Sperry and H.C. Drake in the U.S., experimented with so called magnetic leakage fields. They observed such fields emerging from surface cracks in sections of magnitised rail-road rail.

In 1928, Alfred V. de Forest of the Massachusetts Institute of Technology demonstrated a magnetic particle method inwhich fine iron powder is attracted to a surface flaw in a magnetised ferromagnetic part. The two sides of a crack behave like opposing magnetic poles thus exerting a force that retains the particle at the crack.

Today, the magnetic particle inspection (MPI) method is optimised for particular applications, depending upon magnetisation/ demagnetisation procedures and types of iron powder used. The powder may be dry or suspended in a light oil brightly colored or coated with fluorescent material. This is a simple and economical NDE method for industries that are associated with ferromagnetics, from metal production to field maintenance.

1.4.5 FLUORESCENT PENETRANT INSPECTION

Robert C. and Joseph L. Switzer were the men to introduce the fluorescent penetrant inspection (FPI) process in 1942 and performed experiments in their clivelant , Ohio, Laboratory.

This method emerged as a embracing method for the manufacturer of military aircraft. They applied it to inspect propellers, engine components, castings, bearings and cutting tools. Now being refined, it has become very simple economical and especially well suited to the inspection of complex shaped components for defects that open to the surface.

The part of a test piece, under examination, is immersed in a penetrant liquid bath, an oil or a glicol-based fluid with good wetability and the liquid seeps into open surface cracks. The excess penetrant is made to rinse away and this part is left to dry out. The penetrant trapped in cracks is drawn out by the application of a developer, which acts like a blotter. The result is slightly enlarged replica of the crack, which fluoresces under ultraviolet light. FPI lies across a broad spectrum of manufacturing and maintenance NDE applicability which range from large structures to minute electronic, microcircuits.

1.5 ULTRASONIC TECHNIQUES IN NDT

Ultrasonic techniques have the major advantage that they measure the elastic properties of the material. They also produce data most closely related to a determination of viability and useful life of a material sample. In the past, ultrasonic measurement techniques mainly strived for evaluating the position and size of fairly major defects, such as, cracks or debonded regions. As a present state of art, ultrasonic techniques are applied to measure more subtle characteristics, such as, the size and shape of a crack or defect. The strength of a bond or a residual stress in a welded region or near a crack are also analysed by these techniques.

The basic ultrasonic techniques, employed in NDE, are mostly emphasized on obtaining presence or absence of flaws and afterward getting their images, if necessary while in medical field [4] the use is restricted to the image projection only.

It can be broadly categorised in two parts; holographi and real time (or near real time) imaging systems.

1.5.1 ULTRASONIC HOLOGRAPHY

The aim of acoustic holography [5] is to produce by means of acoustic waves a hologram of an object inside an opaque, subject to transform the acoustic hologram into an optical hologram and to reconstruct from it (by means of light as reference waves) a visible image of the object concerned.

The present, state of the art has not made it possible to construct equipment for acoustic holography which is sufficiently robust and simple to manipulate. It is expected that certain simplifications of the acoustic optical hologram conversion will greatly improve its applicability.

In contrast to the testing of materials, however, it can be hoped that acoustical holography will become an important tool of medical ultrasonic diagnostics.

1.5.2 REAL TIME ULTRASONIC IMAGING SYSTEMS.

The systems are too fast to produce and process a great deal of information in a short time. The imaging devices have been used to search for various types of flaws and have been used in phase contrast to measure stress. At present, only relatively simple demonstrations of real-time imaging have been carried out in the laboratores. But the techniques employed appear to hold great prospects for future applications to NDT [6].

CHAPTER - 2

PRINCIPLES OF ULTRASONIC TESTING

2.1 INTRODUCTION.

In industries, the modern NDE methods are employed to detect defects in component parts and to characterise the physical properties of materials. These methods follow one of the two basic approaches. First one, is the introduction of some form of energy (primarily magnetic, electromagnetic, ultrasonic, thermal, optical, mechanical or penetrating radiation) into a part and the measurement of change in that energy, which is qualitatively related with the defects or properties to be examined. Secondly, one can introduce some type of virtual flaw indicator to the component and produce its visual observation.

2.2 TYPES OF ULTRASONIC WAVES AND THEIR APPLICATION

The classification of ultrasonic waves is based on the mode of particle motion. This categorisation presents four types of ultrasonic waves, longitudinal waves, vertical and horizontally polarized shear or transverse waves, surface waves and lamb waves.

Four of these wave modes with their importance [5], [7], [8], [9] are illustrated briefly in the following paragraphs.

2.2.1 LONGITUDINAL WAVES

These are also called as compressional waves. Their wide application figures in the inspection of metals. The propagation of these waves occurs as a series of alternate compressions and rare factions The particles transmitting the wave vibrate back and forth in the direction of travel of the waves (fig. 2.1).

This is the real ultrasonic wave because it transmits the oscillations of a source of energy through the liquids, solids and even gases.

This type of wave is generally applied for power generation, cleaning in tanks of solvent, dispersal of aerosols and agglomeration of fogs and precipitates, emulsification, grain refinement in steel melts, ultrasonic mechining and in testing and measurement problems. Location of hidden flaws in metallic objects, measurement of the depth of liquid in tanks and determination of the thickness of boiler tubing or heavy castings (where, only one side is available) can all be performed by means of longitudinal waves.

2.2.2 TRANSVERSE WAVES (SHEAR WAVES)

These waves also have extensive use in ultrasonic inspection of metals. The transverse wave phenomenon can be understood by the vibration of a rope that is shaken rhythmically in which each particle vibrates up and down in a plane perpendicular to the direction of propagation (fig.2.2).

Due to the non-propagation of shear waves through gases and liquids (otherwise, they could not flow so readily along walls i.e. through pipes), they find appreciable application in testing of solid materials only.

The above, two waves are plane waves i.e. waves in which a given phase of oscillation is always the same in a given plane. This cophasal plane is the wave surface which moves parallel to itself during the wave propagation.

2.2.3 SURFACE WAVES (RAYLEIGH WAVES)

The so-called, surface waves are another type of waves to be used for inspection of metals. These waves travel along the flat or curved surfaces of relatively thick solid parts (fig. 2.3). The propagation of surface waves needs the wave travel on along an interface bounded on one side by the strong elastic forces of a solid and on the other side by the practically negligible elastic forces between gas molecules. Surface waves, therefore, nowhere exist in a solid, immersed in a liquid unless only a very thin liquid film covers the solid surface.

Although, limited, these waves are utilized in the location of surface defects occuring in beams, spares, axle forgings and other materials which have the dangerous cracks close to the surface. A specific feature of these waves, to flow around corners and over bumps, edges and other irregularities facilitates them to be used in the surface examination of such items as,aeroplane wing-fittings, where access is difficult or impossible.

2.2.4 LAMB WAVES

These are also known as plate waves. These waves propagate in a mode in which the ultrasonic beam is contained within two parallel boundary surfaces (such as plate or the wall of a tube). A lamb wave consists of a complex vibration, occuring **through out** the thickness of the material. Density, elastic properties and structure of the metal are the deciding factor for the propagation of lamb waves. The wave travel is also influenced by the thickness of the material.

There are two basic forms of lamb waves: (a) symmetrical or dilatational (fig. 2.4a) and (b) asymmetrical or bending (fig.2.4b). The form of wave is determined by whether the particle motion is symmetrical or asymmetrical with respect to the neutral axis of the test piece. Each form has its own subdivision in several modes.Different modes have different velocity which can be controlled by the angle at which the waves enter the test piece.

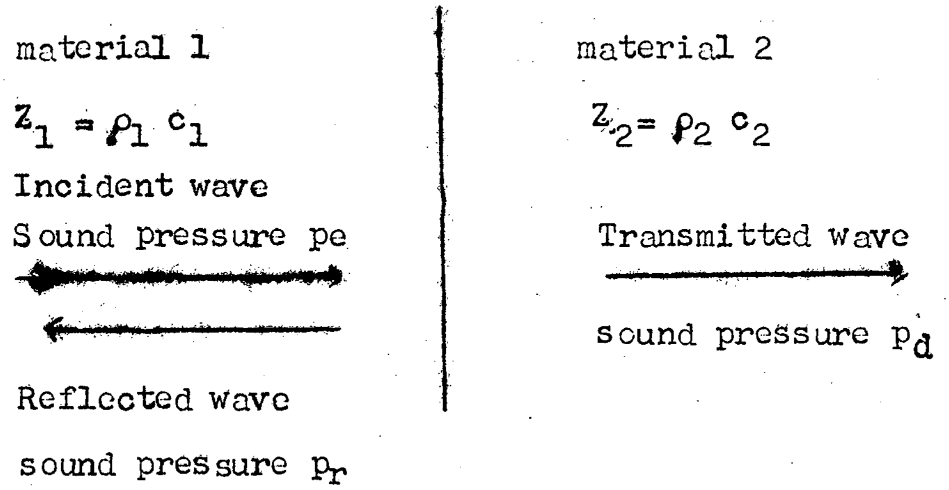
To a limited extent, lamb waves are used in examination of thin sheets and plate stocks. Not much more effort has been made on the development and understanding of the characteristics of the lamb waves.

2.3 ULTRASONIC WAVES AND THEIR INTERACTION AT PLANE INTERFACES

Analysis of a wave in an infinitely extended substance is possible theoretically because in practice, every substance terminates some where i.e. it has a boundary or interface. There occurs the disturbance in the transmission of a wave at such an interface because it requires always the presence of particles for its propagation. The interface may cause reflection, refraction or sometimes scattering. When another material behind the boundary adheres to the first material, so that forces can be transmitted, the wave can be transmitted and also can be propagated in it. It is possible that it encounters a more or less change in direction, intensity and mode.

In a simple case, it may be considered that on a plane and smooth boundary, a plane wave strikes perpendicular to the surface. It is assumed that for the symmetry, the plane waves now propagate at right angles from the boundary viz. a reflected wave, which opposes the incident wave and a transmitted wave.

The simple expressions for sound pressure are visualised as:



$$\frac{p_r}{p_e} = R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

and $$\frac{p_d}{p_e} = D = \frac{2Z_2}{Z_2 + Z_1}$$

where Z_1 and Z_2 are acoustic impedances of the materials and R and D are the coefficients of reflection and transmission, respectively.

In ultrasonics, amplitude (intensity) ratios are measured in decibels (dB). For amplitude of acoustic pressure p(intensity J) the following definitions applies:

$$\text{Ratio in decibels} = 20 \log \frac{p_1}{p_2} \text{ dB}$$

$$= 10 \log \frac{J_1}{J_2} \text{ dB}$$

The formulae for R and D coefficients are also valid for transverse waves. Since the velocity of sound in liquids and gases is zero for transverse waves, a transverse wave gets completely reflected (coefficient of reflection =1) in solid material on its surface with a liquid or gaseous substance.

For transverse wave, the formulae are, therefore, of significance only in case of solid/ solid interfaces.

In addition to the interface between two materials of large dimensions, the double interface as in the case of plate and gap. is of interest for the testing of materials e.g. for the transmission of sound through a crack in a solid body. The wave passing through material 1 gets splitted into a transmitted and reflected wave while striking the material 2. After passing through the plate, the transmitted wave again splits at the second interface and so forth. The result is a sequence of reflections in both directions inside the plate. At each interface a sequence of waves leaves the plate. These waves are superimposed and need their sound pressure to be determined [5].

2.4 ATTENUATION OF ULTRASONIC WAVES

In ideal materials, sound pressure is attenuated only by virtue of spreading of the wave and thus faces no attenuation whatever path it follows. In such a case, the sound pressure of spherical wave (or the sound beam of a probe in the far field) decreases only in inverse to the distance from the source.

Natural materials produce some other effects giving further weakening of the sound. These effects are caused by scattering and absorption. Both of these can be determined by the concept of attenuation (some times, also called extinction).

Scattering of Ultrasonic waves is caused by non-homogeneity of materials. Crystal discontinuities, such as, grain boundaries, twin boundaries and minute non-metallic inclusions, lead to the deflection of small amount of ultrasonic energy from the main ultrasonic beam. Mode conversion in mixed microstructure or anisotropic materials at crystalline boundaries occurs because of slight differences in acoustic velocity and acoustic impedances across the boundaries.

The relation of crystalline size (mainly; grain size) to the ultrasonic wavelength has the key role in scattering. When grain size is less than 0.01 times the wavelength, almost no scattering is encountered.

The second cause of attenuation viz.absorption, is the result of conversion of mechanical energy into heat. During the sound wave propagation through the material, the elastic motion heats it during compression and makes to cool while in rarefunction. As the conduction of heat is a very slow process as compared to ultrasonic waves propagation, thermal losses are incurred and consequently, reduce the energy of propagating wave.

Apsorption effect can, roughly, be approximated as a sort of braking effect of oscillations of the particles. This clarifies the fact why a rapid oscillation faces more energy loss than a slow oscillation. The absorption usually increases as the frequency increases but at a rate much slower than the scattering.

However, in different ways, both losses set limitations to the testing of materials. Weakening of transmitted energy or the echo from both, the flaw and the back wall, is a result of pure absorption. To counteract this effect, the transmitter voltage and the amplification can be increased. Since the lower frequencies cause lower absorption, this fact can also be exploited for this purpose.

However, the scattering pronounces a much more unusuality as in the echo method, it not only reduces the height of the echo (from both, the flaw and the back wall) but also generates numerous echoes with different transit times. These echoes, called as 'grass' some times confuse the true echoes.

It is evident that this disturbance cannot be overcome by stepping up the transmitter voltage or the amplification because the grass also increases, consequently. The only possible remedy is to apply lower frequencies. But it sets a natural and insuparable limit to the detectability of smaller flaws as a result of reduced beaming effect and increased pulse length [5].

2.5 RADIATORS AND REFECTORS

2.5.1 RADIATORS

2.5.1.1 Flat Radiators

This oscillator is in form of a plate and transmits longitudinal or transverse motions to the particle of a contiguous material. The transmission occurs over the entire surface and has the same phase and amplitude throughout this. Such oscillators, being mounted in an extended, rigid wall and radiating into a liquid, produce a sound field similar to that behind a diaphragm (a hole) of the same diameter as the oscillator in the wall. if struck by a plane wave (fig 2.5). The particle motion in the diaphragm is now the same as that immediately in front of the oscillator.

2.5.1.2 Focussed Radiators

The focussed radiators are used in order to increase the sound intensity (power density). The increased sound intensity causes an internal increase in the amplitude of the sound pressure and improves the resolution in certain zones to be examined.

The focussing is realized by means of curved radiators or also plane radiators with contact lenses. Spherical or cylindrical lenses are used according to the shape of the radiators.

2.5.2 REFLECTORS

A given flaw in a test object, e.g. a cavity in casting, acts as an obstacle to the sound wave. The information regarding the flaw can be obtained either via the reflected wave i.e. its echo when using the pulse echo method or by its shadow while using the method of sound intensity measurement.

The obstacles, flaws or defects are termed as reflectors since they reflect the sound wave according to their shape, size and orientation. The dimensions transverse to the beam are the classifying factor of flaws which accordingly categorise them as large or small defects. The name small, however, does not identify the seriousness of the defect in view of the utility of test object.

The simplest form of reflector shape is of circular disc type. The echo generated by this can easily be characterised when it is considered that a circular disc is placed on the axis of the radiator and at a large distance from it. The diameter of the beam, being much greater as compared to disc size, illuminates the circular disc almost uniformly. All the points of disc now become origin of elementary waves which have equal phase and amplitude. Consequently, the disc acts like a new piston oscillator (fig. 2.6).

Natural flaws, in test specimens, differ widely from the artificially, substituted flaws in circular disc form. In general, their boundary is not circular, their surface not flat, nor smooth even if, it could be regarded as approximately flat.

The wave length always decides the rough or smooth features. The surface is considered to be as smooth when the difference in height of the surface irregularities are less than approximately one third of the wavelength.

An appropriate choice of frequency or wavelength improves the reflection produced by rough surfaces. In the case of a longer wavelength, a surface of given roughness may appear smoother and produce reflections like a mirror and thus less scattering. Conversely, a shorter wavelength produces more scattered reflection when incidence is oblique. A broader band of transmitted pulse makes the reflected wave to contain greater information. Thus, very short pulses (shock waves) are of much importance. However, monochromatic pulses having frequency variation over a wide band can also be used. The echo amplitude from the reflector and large plane reflection face is recorded and compared.

2.6 ACOUSTIC DEFINITIONS

2.6.1 ACOUSTIC IMPEDENCE

The ultrasonic waves while travelling through one medium and impinging on the interface of a second medium observe a portion of their energy being reflected from the boundary and remaining part transmitted into the second medium. The characteristic that determines the amount of reflections is the acoustic impedence of the two materials on each side of the boundary.

The identical impedance of the two materials gives no reflection while a great difference in acoustic impedence (as between a metal and air, for instance) causes virtually a complete reflection.

The same characteristic is exploited in inspection of ultrasonic testing of metals. The process provides the information about the amounts of energy reflected and transmitted at impedence discontinuities. This, also, aids in the selection of suitable materials for effective transfer of acoustic energy between components in ultrasonic inspection systems.

Acoustic impedence for a longitudinal wave (z), in Kg-per square meter -second, is defined as the product of the material density (ṅ) in Kg per cubic meter and longitudinal wave velocity (v) in meters per second [1][10].

2.6.2 ANGLE OF INCIDENCE

Only a right angle incidence (normal incidence) on an interface between two materials leads to the occurance of transmission and reflection at the interface without any change in beam direction. The other angles of incidence cause the phenomenon of mode conversion (a change in the nature of wave motion) and refraction (a change in the direction of wave propagation). The entire beam or only a portion of the beam is affected by the phenomenon. The entire changes occuring at the interface depend on the angle of incidence and the velocity of the ultrasonic waves leaving the point of impingement on the interface. The waves propagating at a particular instance depend on the angle of incidence of the initial beam, the velocities of the waveforms in the two materials and the ability of a waveform to exist in a given material.

2.6.3 NEAR-FIELD AND FAR-FIELD EFFECTS

The vibration of the face of a transducer element is very complex. This,in a simple way,can be described as a mosaic of liny individual crystals, each vibrating in the same direction but slightly out of phase with its neighbours. Each element in the mosaic acts like a point (Huygens') source. The point source radiates a spherical wave outward from the plane of the transducer face.

As the distance from the transducer face 'd' increases, the series of acoustic- pressure maximums and minimums become broader and more widely spaced. When d becomes equal to N (with N denoting the length of near-field) the acoustic pressure reaches a final maximum and decreases with increasing distance (fig. 2.7).

2.6.4 ACOUSTIC RADIATION PRESSURE

Acoustic radiation pressure is the net pressure exerted on a surface or interface by an acoustic wave. The sound waves in normal occurance do not produce any net force on an object through the back and forth oscillations of fluid. The sound power of a normal speaking voice is less than one millionth of the electric power of 100W light. Intense sound waves, of course, can exert net forces of sufficient magnitude (proportional to the sound intensity) to counteract gravitation forces and thus levitate an object in air.

The application of acoustic radiation pressure lies in calibration of acoustic transmitters, deforming and breaking up of liquids to collect like objects. This also figures in the positioning of objects in a sound field, some times, levitating the sample so that independent examination of objects properties can be worked out [10].

2.6.5 ACOUSTIC INTENSITY

Acoustic intensity is defined as the average rate of flow of energy through a unit area normal to the direction of wave propagation as a result of sound pressure acting on that area. The units for acoustic intensity are watts per square centimeter or decibels. The energy at any instant consists of kinetic and potential both. The velocity given to the particles of the medium exerts the kinetic energy. The potential energy results from the fact that the particles are displaced from equilibrium and energy is stored in the elasticity or stiffness of the medium.

The power in the sound wave is the product of acoustic intensity and the area through which the acoustic energy flows. This is related to the power input to the transducer. It is a very useful quantity to find out the transducer efficiency [1].

2.7 ULTRASONIC GENERATION AND DETECTION

The ultrasonic transducers (performing both generation and detection) are the devices which convert electrical energy into ultrasonic energy and vise versa. While the detection process is called the direct phenomenon, the generation is termed as reverse. Frequency is the main factor to the selectivity of transducer best suited to any particular application [5]. Piezoelectric effect is predominantly, used for generation and detection of ultrasonic waves. In order to understand their characteristics and applications, a considerable information is produced in the present section. Besides piezoelectric, also, other physical effects can be utilized for generating and receiving ultrasound. Although, not capable to produce comparable signals to the piezoelectric effect, these effects offer a number of advantages and for the same reasons are applied for the testing of materials, in some special cases. In many of these effects, the transmission of energy occurs by electrical or magnetic fields. In such cases, the mechanical contact with the test becomes irrelevant. The conversion into or from acoustic energy is incurred in the surface of the work piece under concern. Surface of the work piece itself forms a part of acoustic transducer in the case of direct method. The direct or dry methods, thus, require no coupling medium and so avoid some of the difficulties arised due to coupling.

In addition to the detailed discussion of piezoelectric effect, all other possible effects, suitable for generating and receiving ultrasound (used for testing of materials) will be be briefly discussed in the following sections:

2.7.1 PIEZOELECTRIC EFFECT

2.7.1.1 Piezoelectric Phenomenon

It is the property of the piezoelectric materials that if deformed by external mechanical pressure electric charges are generated on its surface. Curie Brothers were first to discover this phenomenon in 1880. The reverse phenomenon was discovered soon afterwards (1881).

In reverse effect, such a material changes its form if an electric potential is applied placing it between two electrodes. The former is known as direct piezoelectric effect while the later being termed as inverse piezoelectric effect. The first is now used for measurement leaving the second for producing mechanical pressures, deformations and oscillations.

The piezoelectric effect is a property of the crystal structure and is linked to an asymmetry in it, which can be characterised by presence of one or several polar axes. The each direction of crystal axes differes from the other opposite direction. Thus, a changed state is observed when the front and back ends of such an axis are interchanged.

The piezoelectric effect is best analysed by using plates cut from the crystal at right angles to an X-axis. In this so called X-cut, the z-axis and one y-axis are located in the plane of the plate as shown in Fig. 2.9.

Application of an alternating voltage induces the alternating pressure and radiates a longitudinal wave. The form of the wave depends on frequency and dimensions of the plate and also on the properties of the medium surrounding it.

Occasionally, the y-cut elongation is also used for radiating longitudinal waves from the narrow X-Z face. But this has a particular application for exciting low frequencies because the correlated natural frequency is very much lower than that of the thickness oscillation.

In the case of an x-cut quartz crystal, the transverse waves cannot be transmitted in the X-direction in liquids, nor in solid bodies if coupled to them by a liquid layer. The longitudinal waves are the only waves to be radiated by the crystal in such a case.

2.7.1.2 Piezoelectric Transducer Assemblies

Fig. 2.10 shows the structure of the piezoelectric crystal. It is mounted in a holder and is backed upto the left rear by some material of acoustic impedance Z_b, such as textolite or air. It radiates useful energy to the right front into the load (load may be water, steel, oil etc.) of acoustic impedance, Z_l. The crystal has its own characteristic impedence, Z_t

In a normal way, the testing transducer should be matched as perfectly as possible (accomodating all compromises) from both rear and front sides. The backing material should have a high absorbing coefficient for ultrasound to prevent any amount of reflection back to the crystal [11].

Matching and Damping Layers

It is desired that the transmitting transducer should have maximum efficiency to generate and deliver energy into the material, under examination. The testing transducer desirably, should have a feature that energy incident at the rear interface and passing through the backing layer, is absorbed in the backing layer itself. This feature thus employed, provides maximum damping, fast rise and fall times of the mechanical crystal vibrations and short pulse length of the wave packet. All these factors lead to the accurate and reliable testing and measurement procedures.

The testing transducer assembly is shown in Fig. 2.11. The piezoelement is of ceramic material, such as, $BaTiO_3$. It is faced with a layer of amorphous quartz or sapphire to absorb water. The backing is provided by the multiple alternate λ layers (where λ is the wavelength of the natural frequency of the crystal) of fibre glass and tungsten filled rubber. This ensures an approximate impedence match to the crystal and also absorption of the energy directed towards back from the vibrating element. The transducer so manufactured is heavily damped and of broadband with fast rise and fall time of the acoustic oscillations.

Transition Layers

Transition layers are the material layers sandwiched between the vibrating surface of piezoelectric crystal and its load. This calls for the provision of maximum power transfer in one or both directions or maximum damping. In practice, they are employed in three forms as follows:

1. A thin plate or membrane whose thickness is small as compared to a sonic wavelength.
2. A half wave-length plate.
3. A quarter wavelength plate (acting as an impedence transformer).

Phenol formaldihyde loaded with 30 percent of powdered permalloy is one of the materials used for transition layers.

Backing Layers

In concern to backing layers, testing transducers. designed for accurate rate pulse- work produce a very interesting feature. At a first instance the transition layers are employed to transmit and receive maximum power into and from the load. to achieve maximum sensitivity. Now maximum power transfer needs maximum damping of the crystal at the back to have a minimum ringing of the crystal when the electrical pulse packet gets off. The ideal backing layer should be perfectly absorbing rigid wall which clamps the back face of the piezoelectric slab. A pulse packet with first acoustic pulse having maximum amplitude can be generated only when the back face is fixed.

Kossoff used tungstan powder in Araldite backing material by adding 100-200 g of tungsten powder to 40 ml of Araldite and centrifuging the mixture. Dr. J.U.H. Krautkramer has suggested another backing material i.e. rubber with as much powdered tungsten milled into it as possible. The acoustic impedence of this backing material is controlled by the degree of vulcanisation of the rubber.

The oscillograms of pulses, generated by the application of a fast electrical transient (of the order of microsecond rise time) at 2.5 MHz are shown in Fig. 2.13. This figure illustrates the damping levels, also [12].

Generators Incorporating Direct, Radiating Plane Transducers.

In a practical aspect, the fig. 2.12 shows the typical arrangements. An epoxy resin adhesive (Araldite) used for assembly provides excellent bonds between metals, ceramics and some plastics.

Ceramics, like lead zirconate titanate, are the piezomaterial used. A low impedence backing is provided by the air. In such a way, the entire energy is made available for transmission into the load.

The simplest system is seen in Fig. 2.12a. Here, the front electrode lies between the transducer and the load. The chance of going it wrong is very low but the assembly is rather delicate.

A more robust arrangement is shown in Fig. 2.12b. The transducer in the scheme is protected against the load by a plate (usually of metal) of $\pi/2$ thickness. In the case difficulty lies in umcertainty of a continuous bond between the transducer and the plate. The contained air greatly reduces the transmission into the load and leads to the problem just mentioned.

In practice, the characteristic impedance of the transducer is very different from that of the load but this does not give rise to problems in continuous wave application.

The arrangement shown in Fig. 2.12c, is applied for moderately short pulse work. This has the advantage that the characteristic impedence of the transducer is matched to that of the load by means of a quarter wavelength layer. The precise requirement in perfect bonding and high absorption coefficients is its undesirable limitation [11].

2.7.1.3 Piezoelectric Materials

Among so many materials with piezoelectric properties, mainly; lead zirconate titanate (PZT), barium titanate ($BaTiO3$), lead metaniobate ($Pb Nb_2 O_6$), lithium sulphate ($LiSO_4$), quartz (SiO_2) and lithium niobate($Li NbO_3$) are used for the nondestructive testing of materials. In some specific applications, seignette's salt or rochelle salt (sodium potassium tartrate, abbrebiated KNT crystals), potassium dihydrogen phosphate (KDP), ammonium dihydrogen phosphate (ADP), dipotassium tartrate (DKT), ethyline diamene tartrate (EDT) as well as turmaline, is preferred.

Quartz, the oldest piezoelectric material is pellucid and quite hard. Only a few substances react to it, chemically. The plates which may be dull to clear, depending on the polishing, are cut from natural crystals.

All the other piezoelectric materials are mechanically less resistant. Lithium sulphate (more accurately lithium sulphate hydrate; LSH) is the most critical. The water of crystallasation is removed from it when heated upto 150°C. At this state, it decomposes into powdery lithium sulphate and water. The crystals are made artificially from the solution.

Lithium niobate has the highest curie point and is particularly used for measurements at high temperature. Barium titanate, and lead metaniobate as well as a number of materials on lead-zirconate titanate base (PZT), which resemble barium titanate are used as sintered ceramic materials as it is not possible to produce larger single crystals from them. Unlike quartz, lithium sulphate and the other natural crystals, the ceramic crystals are given piezoelectric properties by polarisation. For this purpose, a direct voltage of a few thousand volts per centimeter thickness is applied to the substance while heating it to a temperature, which is characteristic for each material viz the curie temperature, whereupon the material is allowed to coal off keeping the voltage still applied.

The crystals previously oriented randomly now become aligned along one axis and are frozen. The material remains to be a piezoelectric provided it is not reheated close to the curie temperature. However, its constants may decrease slightly due to ageing. The repolarization of the material can be carried out as and when required. The PZT ceramics have still better electromechanical coupling upto 70 % and higher curie temperature than barium titanate(upto 350°C).

2.7.2 MECHANICAL EFFECTS

The direct mechanical generation of sound,although, not contactless,requires no coupling liquid. Sound, in a body, is produced by mechanical shock or friction. The phenomenon, well known in the audible range, has the wide spectrum in megahertz range. The spectrum depends on the shape, size and material of the objects exposed to the shock. All type of waves are generated by this method. These waves mostly have the frequency range around 100 KHz to 1 MHz. This is the reason why the method is used for testing concrete cast-iron and similar materials. Electromechanical hammers are used while testing the concrete structure

For reception, the effect of sound pressure in liquids is utilized. A receiver, which uses this principle and has found some application, is the Pohlman cell. However, compared with the conventional probes it requires considerable sound pressures and a finite adjusting time.

2.7.3 THERMAL EFFECTS

Thermal expansion of the material produces mechanical stresses when heated suddenly (head shock). The stress initiates sound waves. If the heating is of very short duration (lasting approximately 10 ns), very high frequencies and shock waves can be produced. The main requirement is that the thickness of the heated layer should be small as compared to the wavelength of the sound. Here, also, all kinds of sound waves are generated.

The required energy is beamed into the surface of the concerned object. This is understood in two ways:

(i) By electromagnetic waves (microwaves infrared and visible light) as shown in fig. 2.14.

(ii) By corpuscular radiation (electron beams)

The conversion into heat is affected via several stages which differ in the case of wave and corpuscular radiation. For sudden heating, lasers solve the purpose. successfully since they have the property to be pumped. and releasing their energy by means of a QR switch (Q-switch).

All thermal effects due to their slow reaction are unsuitable for receiving pulses. However, at higher sound energies in continuous operation cholesteric liquid crystals react to heating by sound with a colour change.

2.7.4 ELECTROSTATIC METHODS

The plates of the charged capacitor (fig. 2.15) attract each other by the force F determined by

$$P = \frac{\varepsilon_r S \cdot U^2}{d^2}$$

(ε_r: relative dielectric constant, S: surface of plate, U: applied voltage and d: distance between plates).

The force of attraction is independent on the design of the applied voltage. Consequently, a sound of double frequency is generated when an alternating voltage is applied. To avoid the doubling of frequency, a direct voltage $U_{=} \geqq U_{\sim}$ is applied in addition to the voltage applied to the plates. Since the electrostatic forces, in the case of metals act at right angles to the surface, preferably the longitudinal waves are generated.

Electrostatic forces, utilized for direct sound generation at frequencies from 10 MHz to 200 MHz, produce relatively small sound amplitude. The voltage can be stepped only upto the disruptive electric field strength for having a greater force, varying according to the square of the voltage. The amplitude is not much sufficient to be utilised for pulse-echo operation but at best is suited for resonance operation.

2.7.5 ELECTRODYNAMIC METHODS

These methods, also known as magnetoinductive methods, are based on the Lorentz force. The force, F acts on a charge e when it moves in a magnetic induction field B at a velocity v. The following expressions is applied.

$$F \sim e.v \times B$$

A coil, carrying the alternating current (i) is kept on an electrically conducting body which encounters an induced eddy current of density g(determined by e.v) in the small unit volume dV.

Now the force, $F \sim g \times B$ acts on the volume dV. All the three vectors F, g and B, here, are perpendicular to each other. The current density g opposes the flow of current i in the coil. A particular direction of the direct field produces longitudinal or transverse waves.

If B directs parallel to the surface and F acts perpendicular to the surface, the resulting waves are longitudinal (fig. 2.16a). In case, F acts parallel to the surface and B is at right angles to it, transverse waves are produced (fig. 2.16b).

For reception, a superimposed magnetic field is an indispensable requirement. The arrangement resembles the transmitting mode. Like piezoelectric probes, these are also designed to act as a twin probe for transmitting and receiving ultrasonic waves.

If the unit volume dV moves in response to a force F in the magnetic field B, an eddy current of density g flows inducing a voltage in the coil properly positioned. As similar to the transmission, the direction of the magnetic field determines the reception of logitudinal or transverse waves.

2.7.6 MAGNETOSTRICTIVE METHODS (fig. 2.17):

Almost, all the ferromagnetic materials possess the property to be deformed when placed into a magnetic field. The phenomenon is called magnetostriction.

Linear or volumetric magnetostriction occurs depending whether the volume is constant or varying when under deformation. Linear magnetostriction is much stronger than the volumetric magnetostriction. This attains a saturation value at magnetic saturation of the material. Linear magnetostriction is observed only below the curie temperature while the volumetric magnetostriction occurs above this temperature.

In the case of linear magnetostriction, the deformation occurs mainly; in the direction of the field. The linear magnetostruction is dependent on the magnetostrictive constants. These constants , however, are the function of the temperature, the magnetic state and the previous treatment of the concerned material. The magnetostriction is called as positive or negative depending on the expansion or contraction during magnetostriction. For instance, nickel has a negative magnetostriction while the cobalt, the positive.

The sound waves in magnetostrictive material are received due to magnetoelastic effect since the elastic tensions (sound) influence the magnetic properties. The elastic tensions change the density of the magnetic flux in the presence of a magnetic field. The change in the density of magnetic flux induces a voltage in a coil, placed on the surface of the material under test. It is, therefore, necessary to premagnetise the material by means of an external field. It requires also to shift the working point to the most favourable (steepest) part of the magnetostriction curve. The effect obtained is restricted to the surface due to skin effect. It is, also, must that the direction of the magnetic field coincides with the direction of elastic tensions produced by the sound .

A stray flux appears at the point of crack if the body is magnetised, at right angles to the crack. This shows that the lines of force are densest at the crack on the surface. The stray flux around the cracks gets modulated when sound passes through the body. The modulation results via magnetoelastic effect at the same frequency as the ultrasound. This modulated stray flux is picked up by the induction coil.

2.7.7 OPTICAL METHODS.

This is related to the impact of sound on the light waves. For the same reason, these methods are applied only for reception. Methods have been developed to evaluate the spatial distribution of sound field and making it visible. The subsequent electronic processing requires that the effects are all converted into amplitude modulation of the light. The photo-electric cell is used to pick up the signals thus generated.

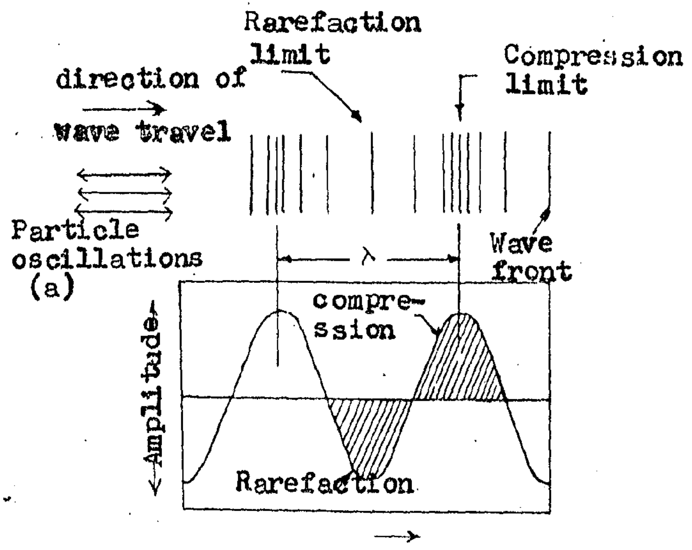


Fig. 2.1 Schematic representation of longitudinal waves

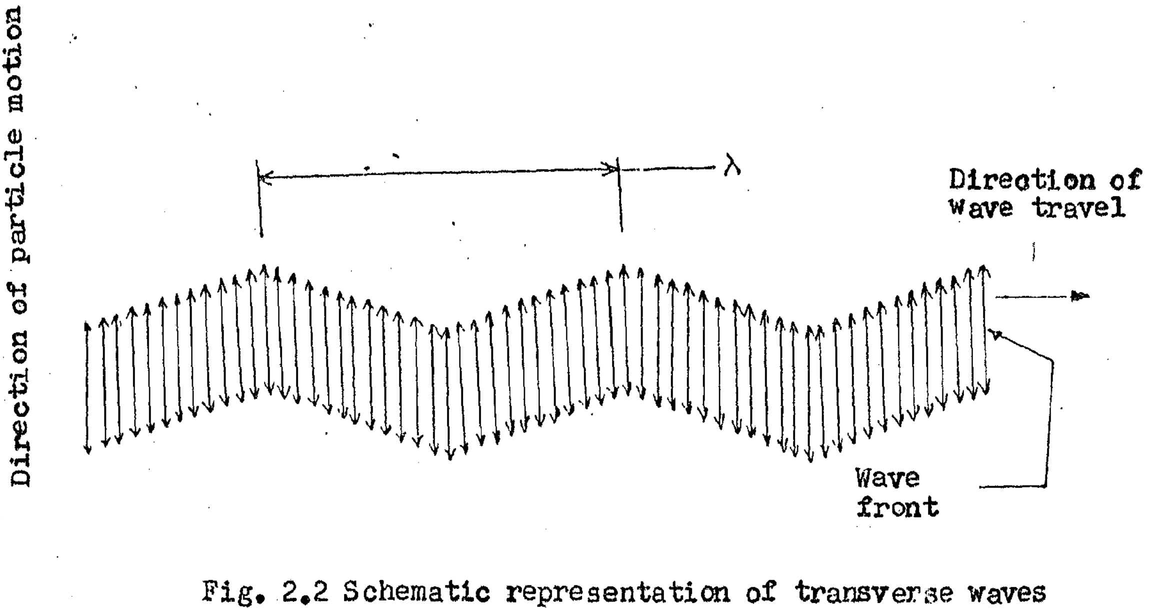


Fig. 2.2 Schematic representation of transverse waves

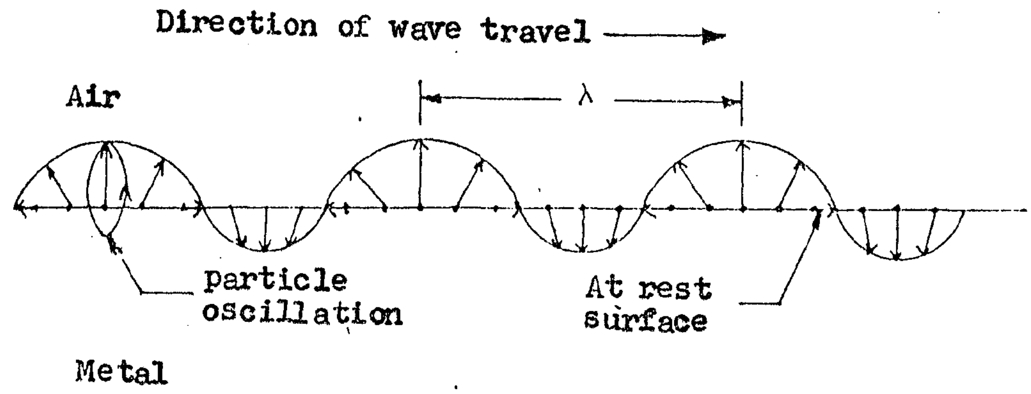


Fig. 2.3 Surface (Rayleigh) waves propagating at the surface of a metal along a metal interface.

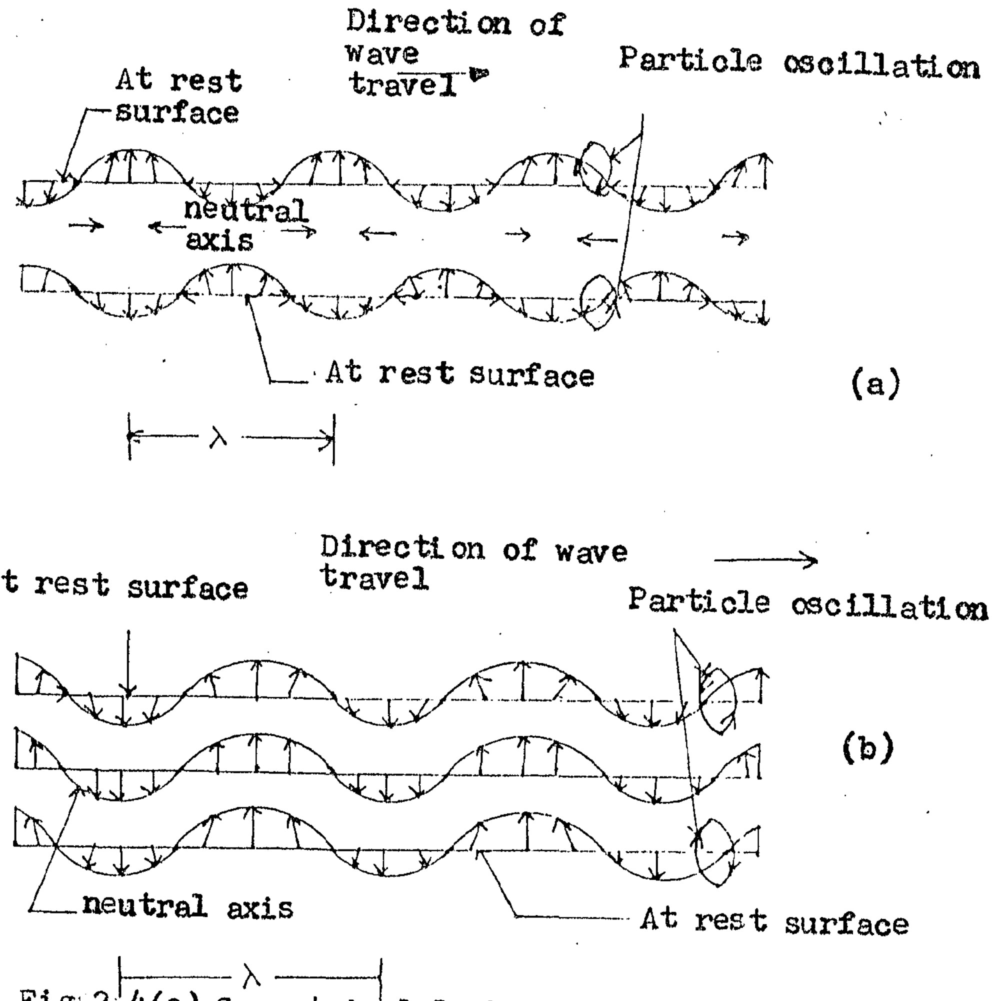


Fig. 2.4 (a) Symmetrical lamb waves,
(b) Asymmetrical (bending) lamb waves.

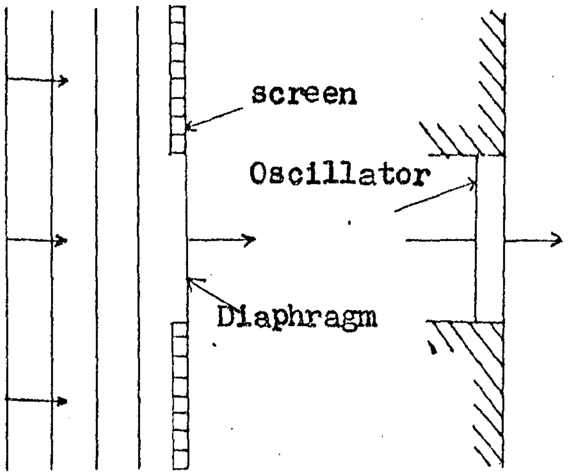


Fig. 2.5 A flat radiator

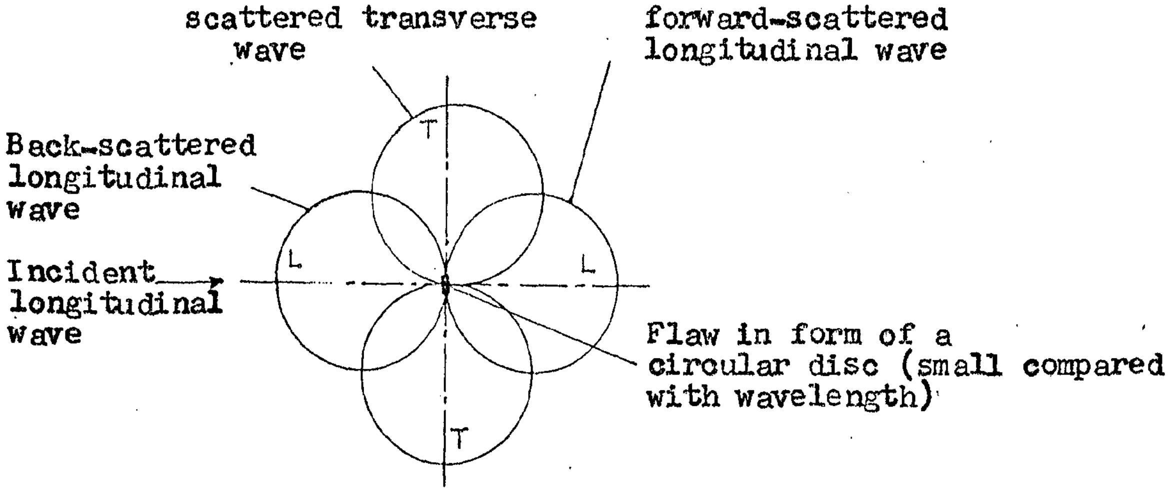


Fig. 2.6 Sound reflection and scatter from a flaw having the form of a circular disc in a solid.

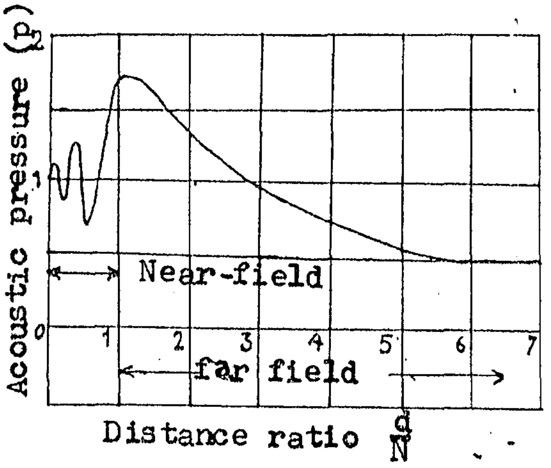


Fig. 2.7 Variation of acoustic pressure with distance ratio for a circular search unit.

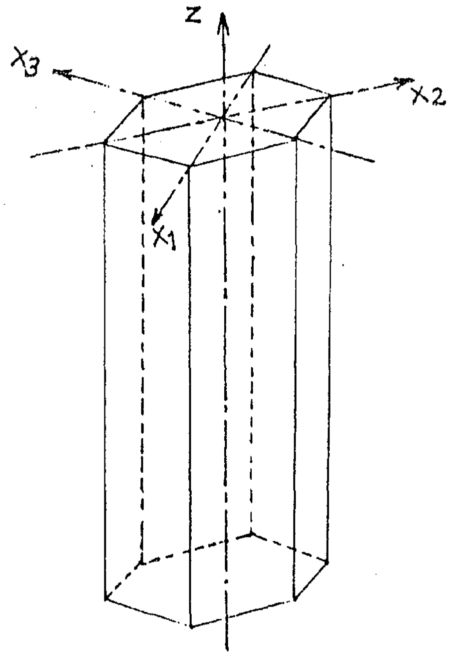


Fig. 2.8 Position of crystal axis in quartz (idealised crystal)

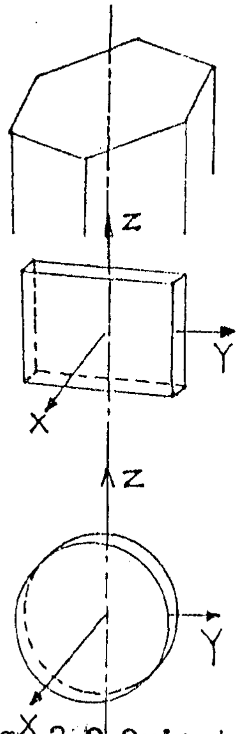


Fig. 2.9 Orientation of sections for rectangular and sound X-cut quartz plates

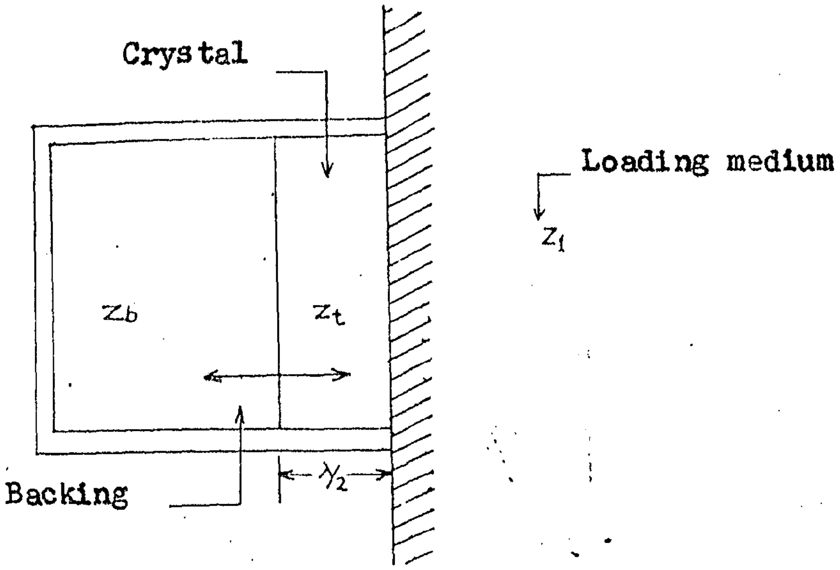


Fig. 2.10 A simple ultrasonic generator.

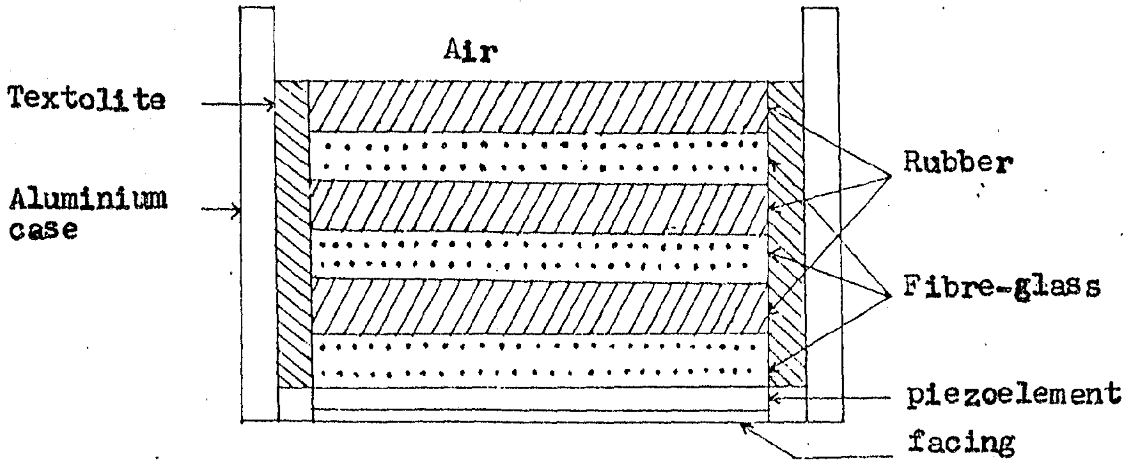


Fig. 2.11 Testing transducer assembly.

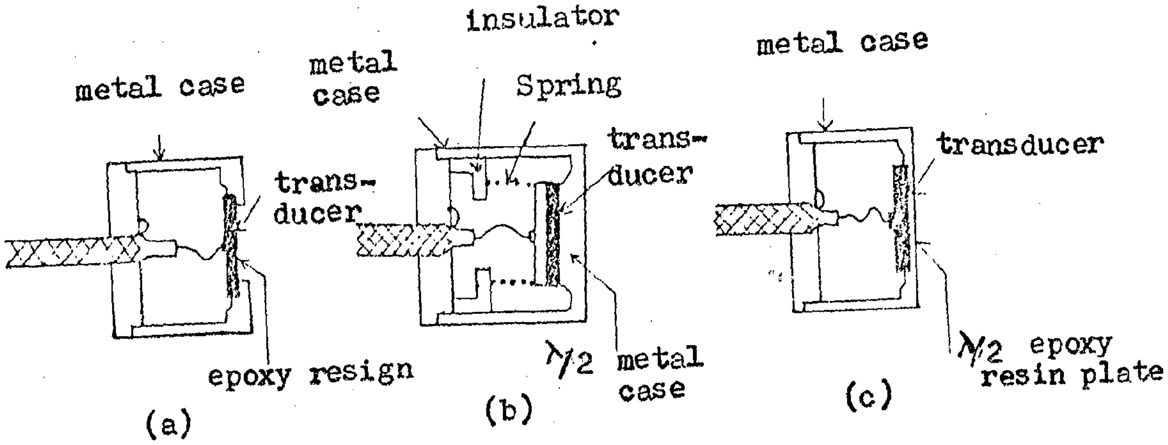
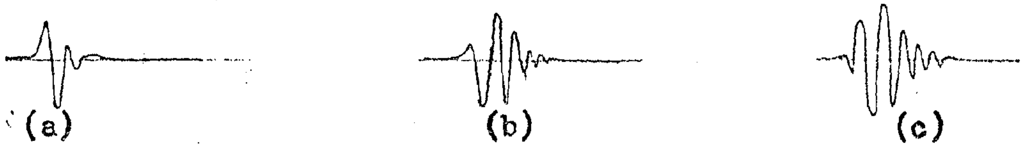


Fig. 2.12 Typical generators



heavy damping intermediate damping light damping

Fig. 2.13 Received voltages for different damping

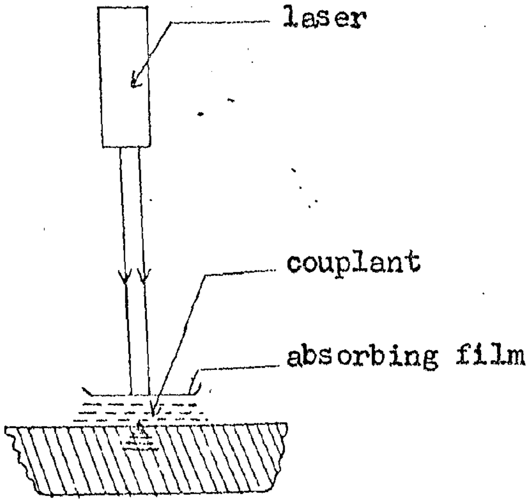


Fig. 2.14 Transmitting probe with laser excitation.

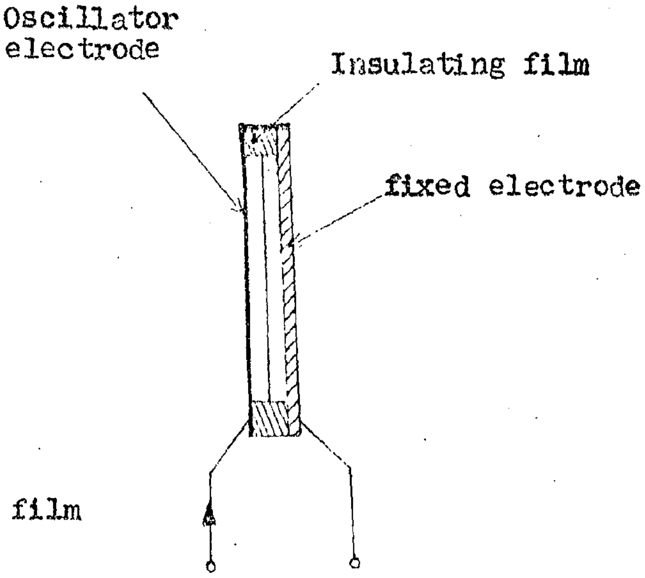
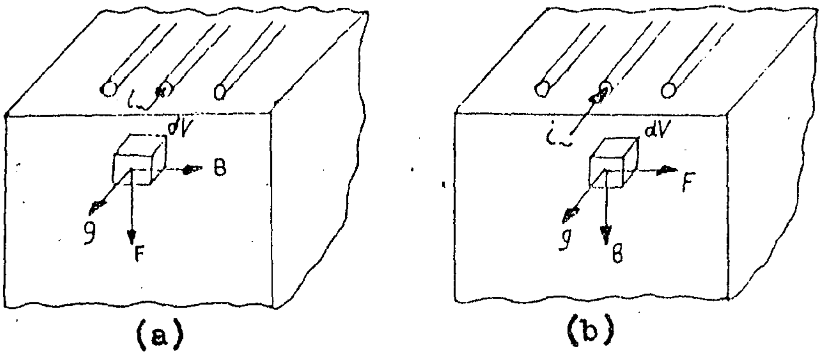


Fig. 2.15 Electrostatic transmitting probe.



(a) (b)

Fig. 2.16 (a) electro dynamic generation of longitudinal waves
(b) electro dynamic generation of transverse waves.

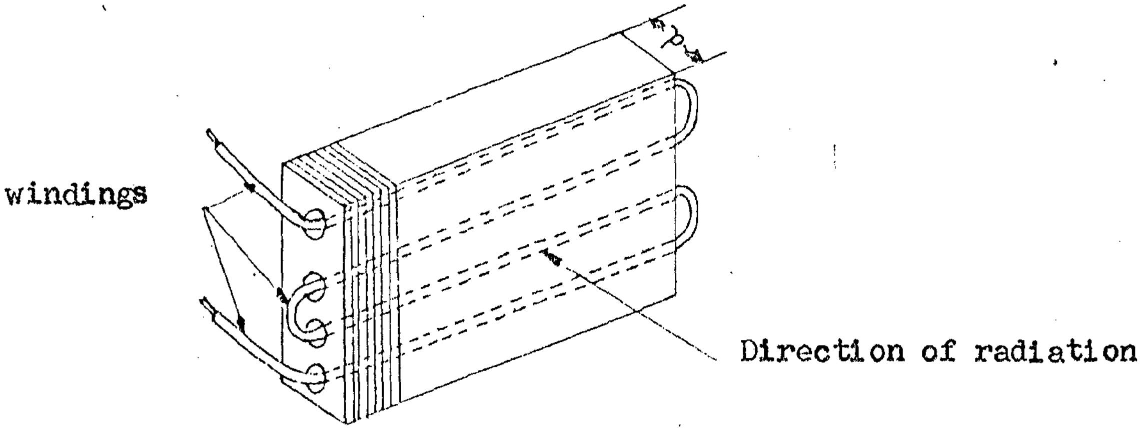


Fig. 2.17 Assembly of a magnetostrictive transducer.

CHAPTER - 3

REALTIME ULTRASONIC IMAGING SYSTEMS (PART-I)

The real time ultrasonic imaging systems, employed in NDT, can be distinctly classified under two categories:

1. Flaw Detection Instruments
2. Wall Thickness Gauging Instruments.

There are different methods for flaw detection as well as for wall thickness gauging. A brief introduction is described in the following sections.

3.1 FLAW DETECTION INSTRUMENTS

These are studied under two categories.

3.1.1 INTENSITY METHOD

Intensity method is the oldest application of ultrasonic waves, used for nondestructive testing. In this method, the intensity of ultrasound is measured after it has passed through the test piece. It was introduced by Sokolov and Mulhauser in 1930. The Fig. 3.1 shows the principle of this method. The scheme portrayes the intensity method by presenting the sound propagation through two test plates. One of these two plates has a flaw while the other is a flawless plate.

The transmitting probe gets excited to ultrasonic oscillations by a voltage produced by high frequency generator. These oscillations are propagated in to the coupled test piece.

A second, coaxially positioned probe receives only a portion of the radiated wave. This further goes to an amplifier of high frequency. The input to the amplifier, which is a high frequency-voltage signal, is proportional to the sound pressure at the contact point of the receiving probe. An indicating type of instrument gives the indication of the amplified voltage. At a flawed point the propagation of ultrasonic wave is obstructed by the discontinuity in the material. Consequently, a reduced sound pressure is attained by the receiver and the measuring instrument shows a lower reading accordingly.

The intensity method can be applied in practice to foun different testing techniques viz.(i) sound transmission [7] (ii) reflection (Fig. 3.2), (iii) conduction and (iv) image projection.

3.1.2 PULSE-ECHO METHOD

The correct name for pulse-echo method is pulse - transit-time method. Since World War I, it figures in the application for locating objects under water. The practical realisation of the method was carried in by Paul Langevin in locating ships; submarines, in particular. During the peace period afterword, the method was applied in the form of Behm's depth sounder for measuring depths at sea. But in the non-destructive testing, it made appearance only during the World War II.

The importance of pulse-echo method for NDT was recognised by Firestone in 1940, particularly in the location of the flaws. Although, the pulse-transit-time method utilises the sound transmission also but the reflection method (fig.3.3) has got a much more considerable importance and consequently, gave the entire method its own name viz. pulse-echo method. In the case of sound transmission, the transit time of the pulse furnishes no additional information concerning any flaws. However, use of pulses prevents from undesirable waves disturbing the simple intensity method.

The Fig. 3.4 shows the screen pictures of flaws for different locations and orientations.

3.2 WALL THICKNESS GAUGING INSTRUMENTS

Wall thickness gauging is the application name of the transit-time method instruments. The instruments based on this method are studied under two categories due to the two different application parameters. The following subsections deal with these methods.

3.2.1 TRANSIT TIME METHODS WITH CONTINUOUS SOUND PULSES

The othername for the method is Resonance method. It is, probably, the oldest of all non-destructive testing methods. It uses the audible sound and is an established old scheme to detect the presence of a crack in a ceramic vessel by its ringing note.

The first thickness tester applying the resonance method was built in 1947 by the Erwin and Rasswellar, General motors U.S.A.[5]. The instrument called 'Sonigage' functions according to the basic diagram shown in Fig. 3.5. A motor drives the rotary capacitor at a high speed. As a result, high frequency is generated varying its frequency at the ratio 1:2 e.g. between 0.75 to 1.5 MHz. At resonance points, the plate current increases and is visioned on the screen of an oscilloscope after processed through an amplifier.

In the method, a given flaw can produce an appreciable effect only if its dimensions are not too small as compared to those of the test specimen. The resonance pattern is incapable to provide position and size of the flaw. For these both reasons, the resonance method finds limited application for flaw detection. However, it is used for thickness measurements and related test problems [1].

The problems mentioned above arise due to the fact that plate under measurement no longer oscillates undisturbed when touched by the probe. The closer the coupling of the probe, the more shift occurs in the resonance frequency towards lower frequencies. This short coming and the recent development in the pulse techniques has out classed the resonance instruments in comparision to the pulse instruments.

3.2.2 TRANSIT TIME METHOD USING PULSES

3.2.2.1 Comparative Method

In the comparative method, the unknown transit time is compared with an accurately known but variable transit time for the same ultrasonic pulse.

As indicated in the fig. 3.6, a second probe having a variable delay line is connected parallel to the delay line under measurement. The delay line, here, consists of a container field with liquid and a reflecting plate. The reflecting plate can be shifted by means of a micrometer. The system is known as 'Interferometer' since the shift is very accurately observed by interference of two echoes on the image screen.

The accuracy increases with the frequency increase. However, this gives the disadvantage that the attenuation and the distortion of the pulse in the test piece also increase accordingly. However, in the case of echo sequence being uniform upto the high multiple echoes, the effect remains at a moderate level.

3.2.2.2 Frequency Measuring Method

This is comprised of the two methods.

The first method utilises the sequence of multiple echoes. The transit time is measured via a frequency, equal to echo repetition frequency. The oscillation time of this frequency viz. its reciprocal value is the desired transit time.

The Fig. 3.7 shows the basic circuit for practical application. The tunable oscillator circuit, here, is connected to the output of the video amplifier, where leads to the measuring plates of the CR tube are also connected. The circuit is tuned to the echo repetition frequency. Every echo in the sequence, causes the inphase triggering of the oscillation circuit, sequencially. The resonance maximum can be seen directly on the image screen. For a given material, the scale of the rotary capacitor can be calibrated directly in transit time or in wall thickness.

The second method, for measuring the transit time, is the sing around method (fig. 3.8). This was proposed and used in 1941 by Hiedermann as the first ultrasonic pulse method. In the method, the returning echo of a pulse triggers the next pulse and so forth. As a result, the echo repetition frequency becomes equal to the pulse repitition frequency. This echo repetition frequency now can be measured with a frequency meter at a very high accuracy as permitted by the instrument. The transit time is the reciprocal value of the repetition frequency. The method, however, presents apparently very accurate absolute values.

3.2.2.3 Electronic Transit Time Measurements

The electronic transit time measurement of ultrasonic echoes is the basis of the most commonly used methods for wall thickness measurement. The determination of wall thickness based on the transit time assumes the sound velocity to remain the same through out the entire thickness i.e. an isotropic material. In addition, the path of the sound is also presupposed to be at right angles to the surface of the test specimen. With the normal probes and isotropic materials, above two conditions are easily satisfied but for TR probes, it applies only when the thickness is not too small.

In the method, transmitting pulse leaving the transducer at the probe stages through a delay line and coupling layer. Afterward it gets splitted into entrance echoes and enters the wall. The backwall reflects the sound pulse, which now onwards passes through the wall thickness in opposite direction. When it reaches at the front of the wall, the part of it leaves the wall and is received by the probe as the first wall echo. The remaining part is reflected and propagates through the wall a second time until the second backwall is reached etc.

3.2.2.4 Phase Measuring Method

The phase method uses continuous waves of constant frequency. For the measurement of transit time, the phase of the echo wave is compared with the phase of the emitted wave. If the transit time interval between front and back interfaces of a given plate is less than one wavelength, it is measured on the basis of phase difference between 0 and 2π by which the receiving voltage is delayed.

For this purpose, very low frequencies can also be used without any difficulty. That is why this method has particular suitability for measuring thickness or acoustic velocities of strongly absorbing materials, such as rubber and plastics. Since the multiple echoes resist the measurement, the method has limited application to strongly absorbing materials only.

3.3 METHODS AND INSTRUMENTATION FOR DOCUMENTATION

Suitable documentation of test results is desirable on the requirement of particular application. Under the pulse echo method, three types of instrumentation schemes for data presentation are widely employed. These schemes are briefly mentioned as follows.

3.3.1 A-SCAN (AMPLITUDE - SCAN)

This is the single axis presentation and provides information relating to distance and number of reflectors or interfaces.

3.3.1.1 Block Diagram and Working

In the scheme (fig. 3.9), the transducer is kept in direct contact with the solid material under test. The contact between the transducer and sample is made with the use of grease or a thin layer of rubber.

Suppose, now the acoustic transducer is excited by a short electrical pulse, the correctly designed transducer then emits an acoustic pulse of length τ_p, determined by its bandwidth ($\tau_p \simeq \frac{1}{\Delta f}$, where Δf is the bandwidth of the transducer). The acoustic impedance discontinuities caused by the presence of flaws reflect the acoustic pulses, passing through the object. The same transducer (in case, acting as transmitter and receiver both) receives the return echo signals and converts them into electrical signal. This electrical signal is amplified and displayed as a function of time on oscilloscope.

The time delay of the echo is $T = \frac{2z}{v_\omega}$, where z is the distance of the flaw from the surface and v_ω is the acoustic velocity in the material under examination. The distance of the flaw from the surface can be determined by the time delay of the observed pulse on the oscilloscope screen. The amplitude of the return echo, also, gives the rough idea about the size of the flaw.

The schematic presentation of the system is shown in Fig. 3.10.

3.3.1.2 Comments and Applications

By locating flaw approximately at the boundary of the near and far field of the transducer, the best result from the system can be achieved. The approximate location of the flaw is selected by the suitable transducer diameter.

Application of A - scan display is not only limited to the detection and characterisation of flaws but it can also be applied for measuring thickness, sound velocities in materials of known thickness and attenuation characteristics of the specific materials. Beam instruments are usually adequate for these purposes. These instruments are also suitable for detecting small cracks, porosity and small inclusion of foreign material within its resolution limit and inspection technique.

Besides conventional pulse- echo inspection with single probe, A -Scan display can also be used with transmission or reflection techniques that involve separate sending and receiving transducers.

3.3.2 B-SCAN (BRIGHTNESS-SCAN)

B-scan display is a plot of time versus distance in which one orthogonal axis on the display corresponds to elapsed time while the other axis represents the position of the transducer along a line on the surface of the test piece relative to the position of the transducer at the start of the inspection.

3.3.2.1 Block Diagram and Working

Unlike, in A-scan inspection, in B-scan, echo intensity is indicated semi-quantitatively by the relative brightness of the echo spots on an oscilloscope screen. A B-scan display can be assumed to be an imaginary cross section through the test piece, where both front and back surfaces are considered in a plane. The informations from reflecting assumed surfaces within the test piece are also assumed in the same plane. The position, orientation and depth of such interfaces along the imaginary cutting plane are also revealed accordingly.

The generation and detection of the flaw location and its size is done in the same fashion as in the case of A-scan. The processing and transmitting parts remain also most similar but differ in their required characteristics as and when. The difference, as have been earlier noted, lies in the conversion of echo intensity into brightness and extension of the transducer movement in one direction perpendicular to the direction of wave propagation.

The basic block-diagram for one dimensional B-scan is shown in Fig. 3.71. Its working can easily be understood with the block diagram.

3.3.2.2 Comments and Applications

In this case, flaw length in the direction of transducer movement. is recorded but the width (in a direction mutually perpendicular to the sound beam and the direction of transducer movement) is not recorded except as the width affects echo intensity and thus, echo image brightness. Because the sound beam is slightly conical rather than being truely cylindrical, the flaws near the back surface of the test piece appear longer than those near the front surface.

The chief importance of B-scan display lies in their capability to reveal the distribution of flaws in a cross sectional plane. Although, B-scan technique finds its application mainly in medical field, in industrial counterpart, it can be used for rapid screening of parts and for selection of certain parts or portions of certain parts producing more thorough inspection as compared to A-scan techniques. Small transducers and high frequencies provide the optimum results, in case of B-scan techniques.

3.3.3 C-SCAN

C-scan records echoes from internal portions of the test pieces as a function of the position of each reflecting interface within an area. In the read out, flaws are superimposed on a plane view of the test piece. The both, flaw size (flaw area) and position within the plane view, are recorded. Flaw depth is normally not recorded, although, it may be measured semiquantitatively, by restricting the range of the depth within the test piece that is under C-scan coverage.

3.3.3.1 Block Diagram and Working

In a basic C-scan system, shown schemalically in Fig. 3.12, the search unit (Transducer) is moved over the surface of the test piece in a search pattern. The search pattern may be of any forms, for instance, series of closely spaced parallel lines, a zig-zag pattern or a spiral pattern (polar scan). Mechanical linkage connects the search unit to X-axis and Y-axis indicators.

The position indicaters feed the position data to the x-y plotter or a similar display device. Echo recording systems may be of varying nature. Some produce a shaded-line scan with echo-amplitude recorded as a variation in line shading while in the other systems, absence of shading follows up the flaw indication. In this case, a black space shows the presence of a flaw.

An electronic depth gate forms the other essential element in C-scan systems. It is an electronic circuit measuring the time of flight and permits the echo signals within the limited range of delay times. The delay time is the interval between the initial pulse to the receiver and the echo pulse received. A proper setting of depth gate excludes the front and back both reflections from the display. Thus, cnly echoes from within the test piece are recorded except for echoes from thin layers adjacent to both surfaces of the test piece. When the depth gate is set for a narrow range of delay times, echo signals from a thin slice of the test piece, parallel to the scanned surface only, are recorded and the signals from other portions are excluded from the display.

3.3.3.2 Comments and Applications

C-scan systems with automatic units, provide for marking, alarming or charting when they incorporate additional gating circuits. The gates can record or indicate informations, such as flaw depth or loss of back reflection while the main display records an overall picture of flaw distribution.

The advantage of the method is that good definition can be obtained and recorded. A high quality transmission image of the street metal and other objects is also observed.

3.4 A-SCAN AND ITS INSTRUMENTATION SCHEME (THE SYSTEM DEVELOPED)

3.4.1 BLOCK DIAGRAM AND WORKING

Earlier (section 3.3.1) we have gone through the basic principle of A-scan on a theoretical background. The block diagram shown in fig. 3.13 is based on the practical considetations and presents the complete instrumentation scheme used at present.

The clock triggers the transmitter, which generates an electrical pulse to excite the transducer. The transducer emits stress waves of sufficient amplitude to meet the requirement. The output signal of the transducer is fed to the radio frequency amplifier . The gain of this RF amplifier may be increased with time to counteract the increasing attenuation of the echoes from deeper structures. The swept gain circuits are triggered at the same instant when the ultrasonic pulse is transmitted. The ramp generated by the time base circuit deflects the trace at constant velocity appropriate to the penetration. The output from the rf amplifier is demodulated. The dynamic range of the instrument thus,may be limited by suppression of smaller echo signals, fed to the video amplifier at its next stage. The output from this amplifier is connected to the y-deflection plates of the cathode ray tube. The obtained display at CRO screen, in such a way, is known as A-scan.

3.4.2 DESIGN CRITERIA

The various elements of A-scan instrumentation are as below:

1. Clock
2. Transmitter
3. Swept Gain Generator
4. Time Base Generator
5. RF Amplifier

6. Demodulator and Suppressor

7. Video amplifier

The design aspects based on their required characteristics are discussed as following:

3.4.2.1 Clock

The rate generator or clock provides the trigger pulses which control the repetition frequency of the system. The particular application decides the frequency which may range from 25 to 3000 Hz. The frequency stability of the clock is not of much importance since all the other timing circuits operate in synchronism with the trigger pulse which it generates. Astable multivibrator is mostly employed as rate generator.

For the system developed, here, IC 555 timer has been used in astable mode [13]. The frequency of it can be changed as and when required by varying the capacitance or the resistances, being connected in particular configuration, shown in fig. 3.14.

Intervals of the pulses are normally kept 60 times of the operating time to avoid the phantom echoes [5]. The operating time for the 555 is given as

$$ta = 0.693\ (Ra + Rb)\ C$$

and $$t_p = 0.693\ R_bC.$$

where t_a and t_p are the on (operating) and off times of the timer. The value of Ra is kept more than 1 K ohms while sum of Ra and Rb is in range of 1 K ohms to 20 M ohms.

Thus, with variables Ra, Rb and c, one can have varied frequency range, here, as stated above.

3.4.2.2 Transmitter

The transmitter function is to drive the transducer in such a manner to produce controlled acoustic pulse shapes at a sufficient intensity level [14].

The length of the pulse, generated by the ultrasonic transducer, plays a key role in determining the resolution of flaw detection and thickness gauging systems. The shorter the ultrasonic pulse length, the better is the resolving power for closely spaced defects. The 'grass', generated due to scattering from grain boundaries, creates problems to distinguish the defect signals. In case of A-scan display, short acoustic pulses, however, make it possible to identify these defect signals [14].

At present, to shock excite the ultrasonic transducer, the circuits generate a step voltage across it. This is obtained by discharging a capacitor(previously charged to a few hundred volts) into the transducer capacitance. To discharge the capacitor, the thyristor or avalanche transistors are used as the switching element.

The circuit as shown in Fig. 3.15, designed and developed , employes the medium power transistor SL 100 as the switching element. It is supplied with 50V at the collector through a resistance. The fast leading edge of the pulse depends on the turn on characteristics of the transistor and the recovery of pulse depends upon the time constant RC.

3.4.2.3 Swept Gain Generator

The attenuation of the ultrasonic waves and consequently of the echoes increases with distance. Therefore, some compensation must be provided to acknowledge their presence. Compensation for attenuation can be partially provided by the application of a swept gain. Swept gain is a method by which the gain of the receiver is increased with time. As a result, the echoes from inner structures are amplified more than those which are produced nearer to the transducer and so arrive earlier in time.

The maximum useful signal dynamic range after swept gain compensation lies in the order of 30 dB. The limited dynamic range of the transducer puts a restriction to the above dynamic range, in case the very small echoes precede very closely to the echoes of large amplitude.

The swept gain generator as shown in Fig. 3.16 uses a FET, of which drain-to-source impedance varies in accordance with the negative voltage applied to its gate. The voltage signal, being fed to the gate, is achieved by an integrator circuit. Its maximum value is determined by the time constant RC. A bijunction transistor provides the switching action.

3.4.2.4 Time Base Generator

This generates the sweep voltage for the CR tube at the same frequency at which the transmitter transmits high frequency pulses to the probe. The duration of the operating time (during the operating time sweep voltage rises linearly and thus, shifts the electron beam from left to right) is determined by the testing range. The transmitter pulse and various return echoes in succession are required to be displayed in vertical plane on this horizontal sweep. The time base should be capable of generating sweep time to cover the depth of material to be examined [12].

The time base, here, is produced by an integrator circuit (fig 3.17). Its maximum value is determined by the time constant RC and sometimes by the frequency of the pulse fed to the integrator. The switching action, here, again is achieved by a Bijunction transistor.

3.4.2.5 Radio frequency Amplifier

The range resolution of a pulse- echo system is determined by the total bandwidth and dynamic range of the system while keeping all other factors equal. The bandwidth is limited by the performance of the transmitter, the transducer, the receiver and the display. However, display is not the limiting factor for bandwidth but has importance in relation to dynamic range.

As the frequency response widens, the range resolution becomes better. However, signal-to-noise- ratio of the system depends upon the bandwidth [15]. Thus, a compromise between bandwidth and sensitivity is needed. For a satisfactory response, the rf amplifier bandwidth is made equal to zero crossing frequency of the ultrasonic pulse and the passband is arranged to be centered on this frequency.

A radio-frequency amplifier for ultrasonic pulse echo applications needs to satisfy the following requirements.

i. adequate gain-bandwidth product at low noise
ii. selectable centre frequency if appropriate
iii. low phase distortion
iv. appropriate amplitude response
v. quick recovery from over load
vi. ability to withstand transmitter output, and
vii. provision of swept gain.

When a multistage amplifier is used with the use of a few (usually two) syncronously tuned stages of moderate bandwidth amplifier, a wide frequency response can be obtained. The integrated circuits designed for radiofrequency applications meet the first three requirements. The amplitude response of the radiofrequency amplifier may be linear or it may have a signal compression characteristic to reduce the dynamic range.

To become paralysed is an unwanted feature of the receiver. This causes a long transmission pulse and thus a lower resolution. Paralysis is the phenonenon under which amplifier becomes insensitive to small signals until the biasing conditions, previously changed by overloading signal, return to the normalcy. The paralysis effect can be minimised by making the capacitors (controlling the biasing) so large so that overloading signals can produce only small changes in the operating conditions. The other way is to make such arrangement that the gain of the system remains low at the time of occurance of the largest signal., to the amplifier input.

A limiting circuit, incorporated at or near the input to the amplifier, reduces the problem of paralysis. In the system developed here, the peak input to the receiver is limited to 0.7V, which is the forward voltage of the reverse connected diodes (fig. 3.18).

The requirement for swept gain depends upon so many factors. There are two methods to obtain a swept gain. In the first method, the gains of the appropriate stages are controlled by the alternation of feedback or biasing conditions (The feedback resistance alteration is implemented in the present system Fig.3.16)

In the other method, the gain of each stage of the rf amplifier is kept constant and appropriate attenuation controlled electronically, is introduced at different points in the circuit.

The operational amplifier LF 356 furnishes an useful RF amplifier stage when considered with the compromise between its bandwidth and noise conditions.

3.4.2.6 Demodulator and Suppressor

The dynamic range of the output signals from the rf amplifier is in the range of 30 dB. For further amplification and processing these signals are needed to be demodulated. Demodulation in the ultrasonic systems is usually carried out by means of a suitable diode network as shown in Fig. 3.19.

The lower limit of the signal dynamic range is determined by the non-linearity of forward characteristics of the diode demodulator. The upper limit is controlled by the maximum output voltage, available from the rf amplifier, provided that the forward current and reverse maxima of the diode characteristics are not exceeded.

The effect of the non-linearity of the demodulator is minimised by increasing the total value of (R_S+R_L). This improvement is also limited by some practical factors. The upper limit of the value of R_L is fixed by the input impedence of the video amplifier, which generally is in the order of 1 K ohms.

The process of dynamic range restriction is known as suppression or rejection. The non-linear demodulator action is just equivalent to suppression. The small amplitude signals become relatively small because the dynamic range is expanded by such demodulators.

In practice, the demodulation and suppression is achieved by trial and error method, in which the most appropriate value of capacitance and resistance and suitable diodes are installed at various amplifier stages. The same method applies here, too [11].

3.4.2.7 Video Amplifier

The demodulated output from rf amplifier has amplitude of around 1V peak. These signals are video signals having useful dynamic range in the order of 30 dB. These signals need to be amplified to a level appropriate to drive the particular display device in use.

The video amplifier designed should fulfill the following conditions.

(i) adequate gain to drive the display when the input signal is of the smallest value of clinical significance.

(ii) adequate bandwidth to maintain the pulse characteristics unless it is deliberately intended to process the signal for example by differentiation; and

(iii) dynamic range compression to avoid overdriving of the display with large amplitude signals. This may be achieved by limiting the maximum value of the output of an otherwise linear amplifier, or by logarithmic amplification.

For the video amplifier response, being cut off at a frequency in the range of 10-100 KHz so many problems arise. Such an awkward response results in a serious degradation of long pulses and the recovery time becomes large when followes a large signal.

The operational amplifier LF 356 here also meets these above mentioned requirements. So the same operational amplifier is used also at the video stage amplification.

3.5 FLAW LOCATION IN NUMERICAL READ OUT

We know that the transit time for return echo depends on the flaw location from the surface of the transducer (coupled to the test piece). It leads to calibrate a numerical display device which gives the flaw position in distance units.

For numerical read out the two methods; integration method and counting methods are applied. A brief discussion is given as below.

3.5.1 INTEGRATION METHOD

In the integration method (fig. 3.20), transit time is converted into a voltage signal. The reading edge of the square pulse (Transmitted and received echo pulses are converted to a square pulse) connects a stabilised current source to a capacitor and charges it. The voltage on the capacitor rises in proportion to the transit time. This is interrupted by the trailing edge of the square pulse. The proportionality constant for voltage build-up and gradient of the voltage curve can be adjusted on the basis of the requirement of current intensity change. The change in intensity of the current occurs according to the velocity of sound and the range of measurement.

For further processing, the voltage obtained in this way is preferably, stored in a holding circuit (until, after arrival of the next transmitting pulse, a fresh square pulse is generated). During the storage time, the voltage given to an indicator or recorder is in analog form. With the use of an analog to digital converted (ADC) the measured value can further be processed for a digital display or coded signal read -out.

3.5.2 COUNTING METHOD

It is purely a digital method. Fig. 3.21 shows the block diagram along with the waveforms. The unit of time is the duration of one period of an oscillator frequency. The oscillator frequency is selected on the basis of the velocity of sound and the required accuracy of the transit time.

The counter is fed with the oscillator frequency. The counting starts at the leading edge of the square pulse and steps at its trailing edge (fig. 3.21). The counting result then describes the number of base units corresponding to the transit time. The measured digital value is stored and displayed digitally. It is also made available for further processing e.g. in BCD coded form.

A comparision of the integrating and counting method implies the following conclusions.

The both methods require determination of a quantity which corresponds to the acoustic velocity in test piece viz. the integration time constant or in the latter case the oscillator frequency. The former has the advantage of continuous adjustment. The latter is based on the high stability of quartz. The oscillator frequency, in this case, can be adjusted to discrete values only, which of course, is achieved only by exchanging oscillators.

3.5.3 THE DEVELOPED DIGITAL READ OUT SYSTEM

The counting method has been used for the present scheme. The oscillator is a crystal controlled, producing frequency of 3.579 MHz. This frequency, for brass material application is divided by 2, in case the accuracy to mm. units is needed. It is divided by 20 to get the reading in cm scale. All these division scales are applied for pulse- echo method only i.e. in reflection mode. For the transmission mode the frequency may be divided by half of the numerical value applicable in reflection mode.

The block diagram shown in Fig. 3.22 clearly depicts the complete scheme for digital read out. The first requirement, in this case, is to get the transmitted and reflected pulses, squared. In the second step, the reflected pulse is extracted out from the combination of these two pulses. With the transmitted pulse and the reflected echo pulse, we generate a square pulse of length equal to the transit time for first return echo. As indicated in the just earlier section, the pulses to be counted are fed to the counter, only during this interval. The final count is latched and displayed on the seven-segment LED (in BCD form) after being decoded by four to seven segment decoder.

3.6 PRETESTING PROCEDURES

3.6.1 CONDITION AND PREPARATION OF SURFACE

The shape and roughness of the surface has a decisive role in all the ultrasonic tests. These factors often limit the sensitivity of the method applied. Thus, they provide for the need of a well prepared surface. When probe is in direct contact with the test piece, its wear is being much influenced by these factors. It gives a conclusion that the economics of testing is greatly influenced by the surface conditions.

For reliable flaw evaluation, a uniform surface condition is desirable. The thickness of the coupling liquid field is varied considerably when foreign particles or layers exist between the probe and the test piece. Transmission of waves is also not identical for all points on the surface. Thus, it is of utmost requirement to remove any dirt, loose scale and sand. Rags, contton waste and steel brushes are utilized. for the purpose. In case of loosely adhering layers of rust or paint, scrapers are used. Thin oxide layers or even paint are sometimes, preferred to an unevenly cleaned surface.

3.6.2 COUPLANT

Air is a poor transmitter of sound waves at mega - hertz frequencies. Transmission of sound waves is greatly retarded even in the presence of a ray thin layer of air. To have a satisfactory contact couplant is used between transducer and test piece. Couplant, normally, used for contact inspection include water, oils, glycerin, petroleum greases, silicon grease, cellulose gum and various commercial paste like substances. In case, the soft rubbers are used for coupling, adequate coupling needs some pressure to be applied at the transducer.

The following points are considered while selecting a couplant.

1. Surface finish of test piece.
2. Temperature of test surface.
3. Possibility of any chemical reaction between test surface and couplant.
4. Cleaning requirements (some couplants are difficult to remove)

Water serves as a suitable couplant for use on a relatively smooth surface. However, a wetting agent is added to it. Some times, glycerin is also used to increase its viscosity. Heavy oil or grease should be used on hot or vertical surfaces or on rough surfaces where irregularities need to be overlooked.

Cellulose gum is especially, suitable for rough surfaces. Here, good coupling is required to minimise the background noise and to have high signal-to-noise ratio.

3.7 RESULTS AND COMMENTS

It has been earlier mentioned (section 3.5.3) that the present system applies the counting method (section 3.5.2) for digitalread out. The photographs, P_{11} and P_{12}, show these readouts for different flaw locations. P_{11} shows that the flaw is present at 35 cm (A brass bar, of length 35 cm, has been taken as sample) while P_{12} shows that the flaw exists at 70 cm from the transducer face (A brass bar, of length 70 cm, has been taken as sample). For these two cases, the clock input signal, for particular interval (decided by the flaw location of back wall echo) can be seen in P_9 and P_{10} photographs. The pulse interval (pulse duration) clearly identifies these two different cases.

The clock signal to excite the transducer at particular pulse reflection frequency is shown in photograph P_1. This also has the differentiated signal, fed to the transmitter input. The negative going edge of this pulse has been clipped off. The two comparative voltage signals for the transmitter output, fed to the transducer, can be observed through photographs P_2 and P_3. While P_2 is the picture for unconnected probe condition, the P_3 presents the same, for the condition when probe is connected across the transmitter. In the former, the maximum voltage of the spike pulse is 36 V while the latter has reduced voltage level to 10V .

The output at the radio frequency stage is realized in P_4. The final output after the complete processing through the vidio amplifier and demodulation and suppression can also be seen in the same photograph. This spike signal is converted to rectangular pulse signal. Signals at intermediate stages (i.e. ANDed output and EX-ORed output) can be identified through photographs P_5 and P_6. The interval pulse i.e. the transit time pulse for two different flaw locations (brass bars of two different lengths) is screened in P_7 and P_8. The photograph P_7 represents it for 70 cm while the other P_8 photograph describes the same for 35 cm.

It has been pointed out that the most important factor for resolution of this system is the damping of the transducer.

The present system is insensitive to search the flaw for a distance, less than 30 cm from the transducer face or to detect the flaws in between two flaws, being 30 cm apart. This limitation is only due to the low damping of the transducer.

In the digital readout, it is seen that instead of reading 35 cm, the system reads 37 cm. The same is true for another case of flaw lying at 70 cm. This difference in the reading, is caused by the inaccurate calibration of the system clock, in consideration to the velocity of sound in brass material. By selecting a suitable clock and adjusting it to exact calibration, the exact position of the flaw can be measured.

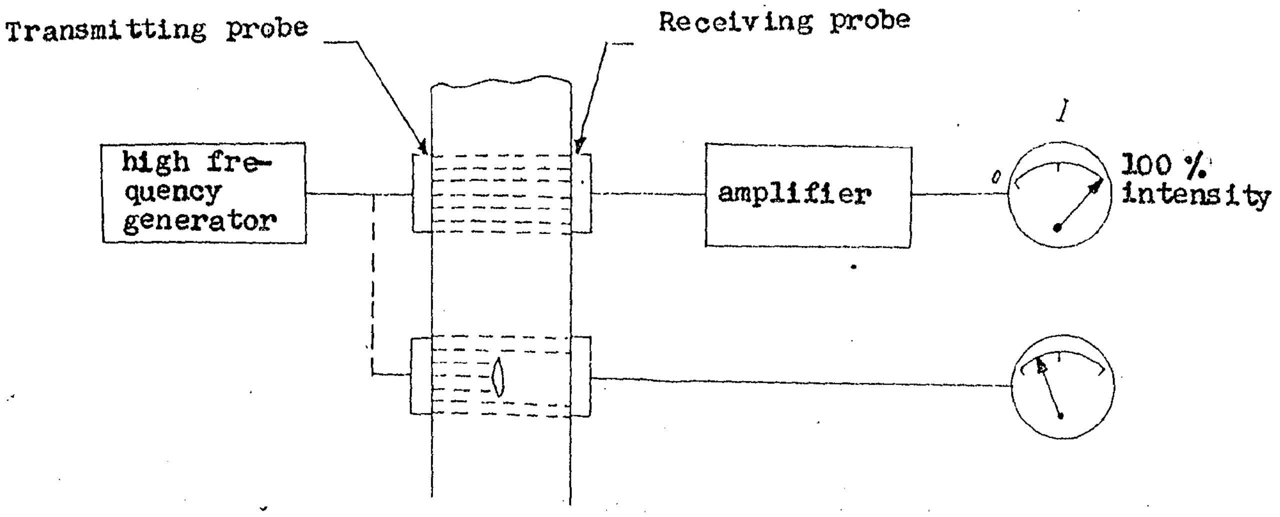


Fig. 3.1 Intensity method with sound transmission

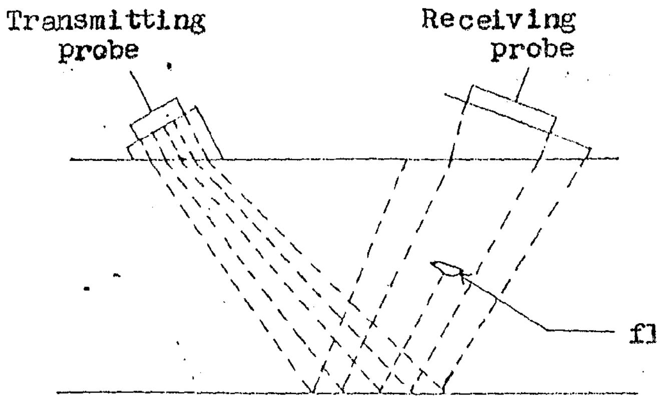


Fig. 3.2 Intensity method with reflection

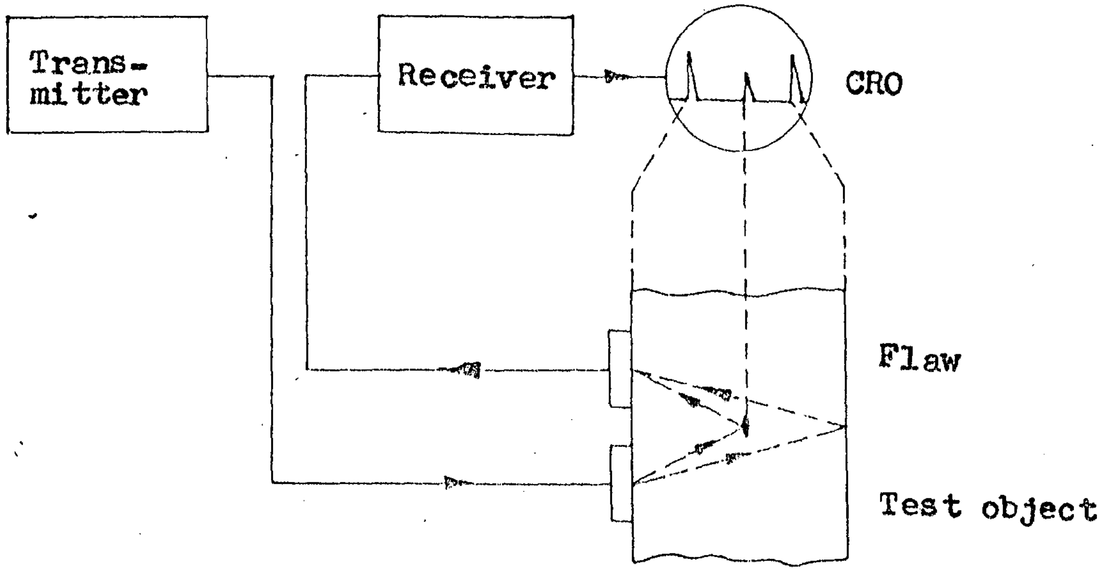


Fig. 3.3 Basic Pulse-Echo Method.

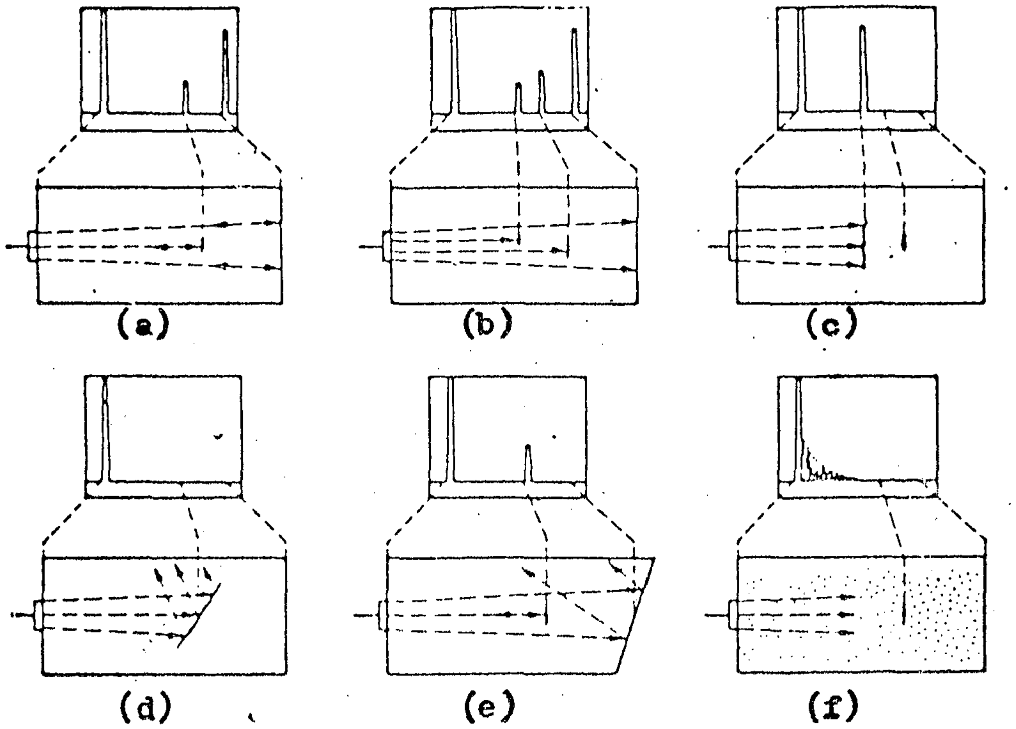


Fig. 3.4 Schematic pictures obtained by the pulse-echo method.

(a) Small flaw in sound beam,

(b) Two small flaws in sound beam,

(c) Large flaw in sound beam, smaller second flaw and back wall masked,

(d) Large obliquely oriented flaw, back wall masked,

(e) Small flaw but not back wall echo, because the exis of the beam is not incident at right angles on back wall,

(f) Strong attenuation of sound beam due to scattering, no echo from flaw or back wall, only 'grass'.

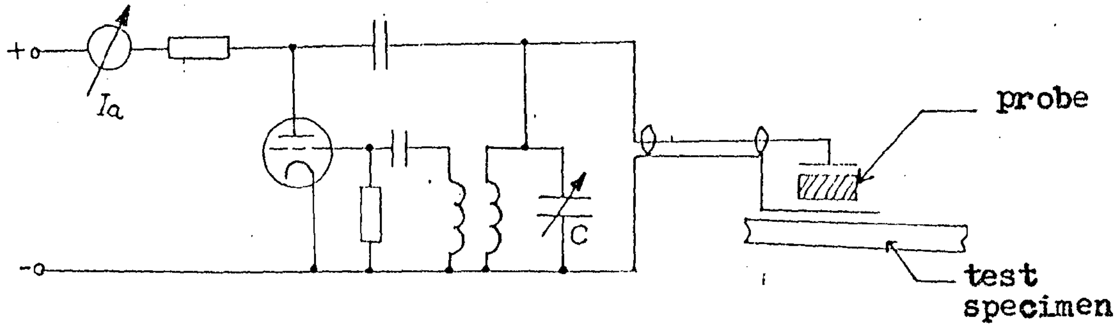


Fig. 3.5 Circuit diagram of a resonance thickness meter.

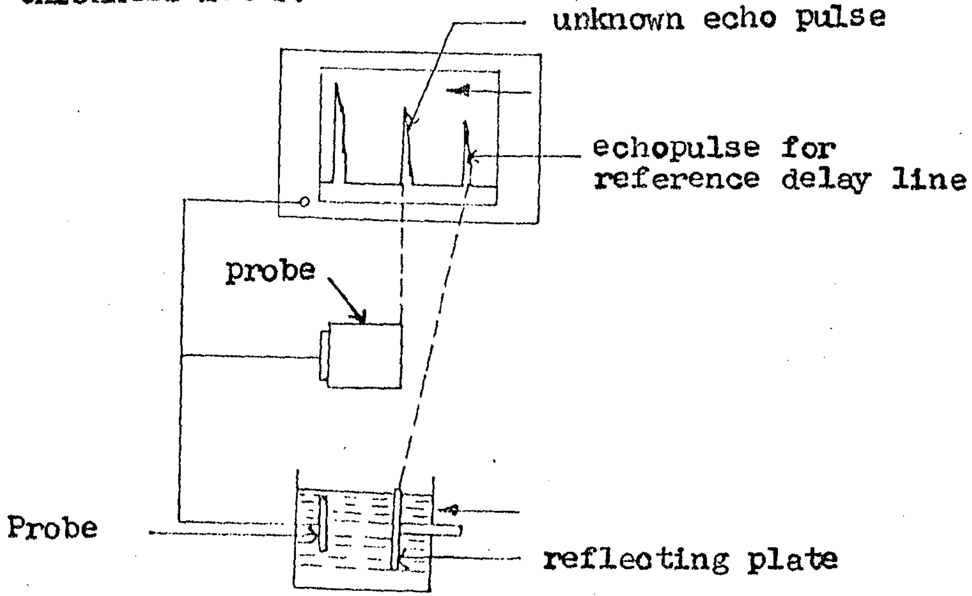


Fig. 3.6 Reference liquid delay lines with adjustable reflector (comparative method)

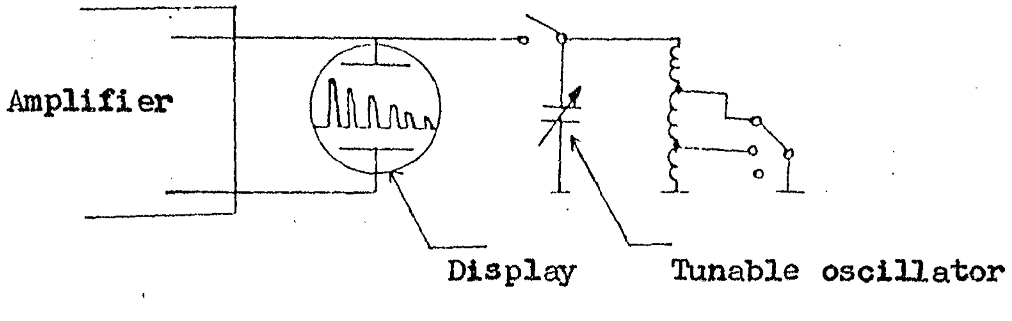


Fig. 3.7 Basic circuit of the wall thickness gauge attachment.

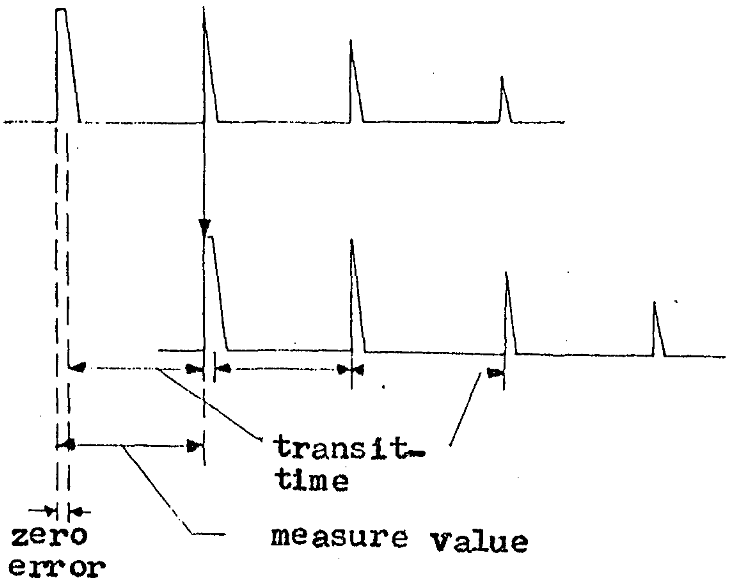
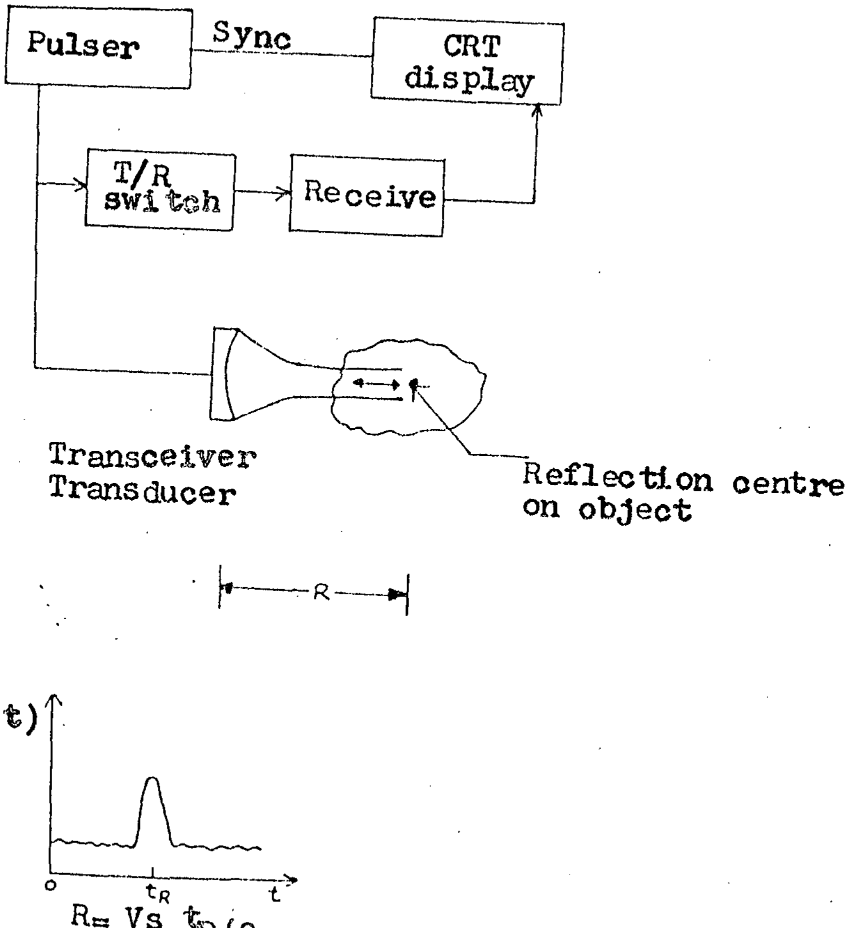


Fig. 3.8 Principle of sing around method for measuring the transit time and its systematic error.



$R = V_s\, t_R/2$

V_s = sound speed in material

$A(t_R) \propto$ flaw size.

Fig. 3.9 A- Scan (a) Block diagram
(b) signal analysis concept.

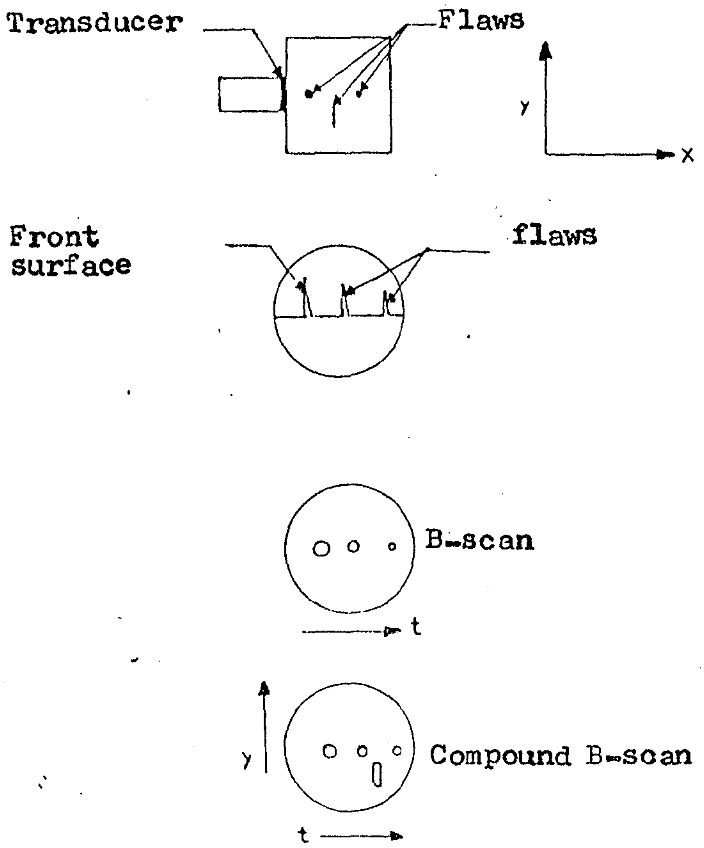


Fig. 3.10 A schematic of A and B-scan operations

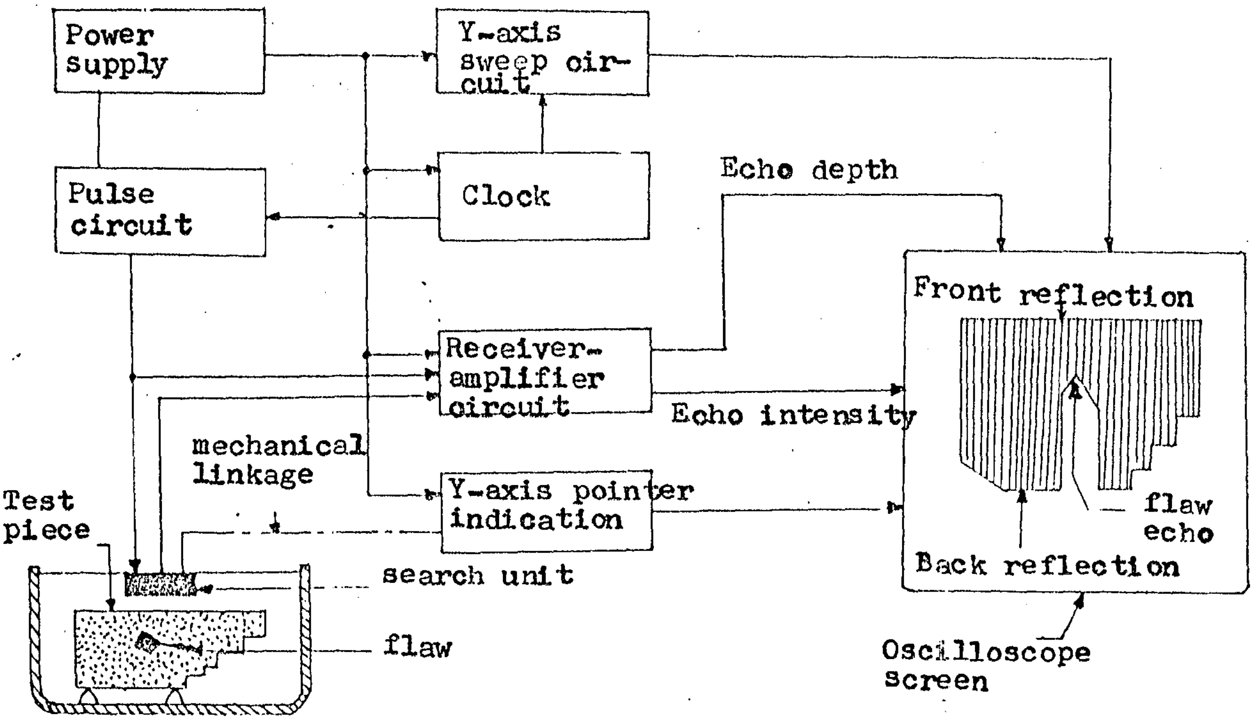


Fig.3.11 Typical B-scan set up, including video mode display for a basic pulse echo inspection system.

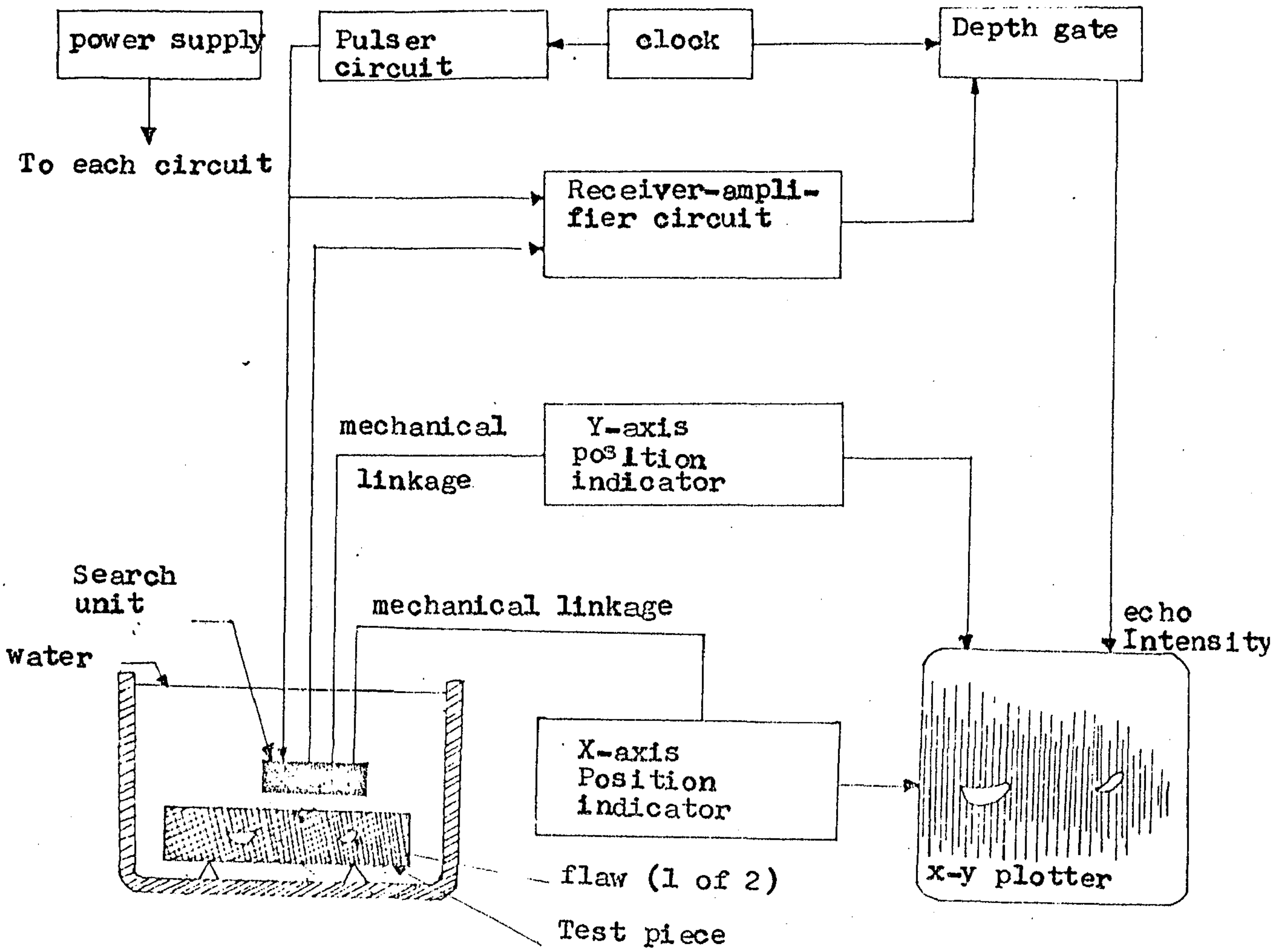


Fig. 3.12 Typical C-scan set put, including display for a basic pulse-echo ultrasonic inspection system.

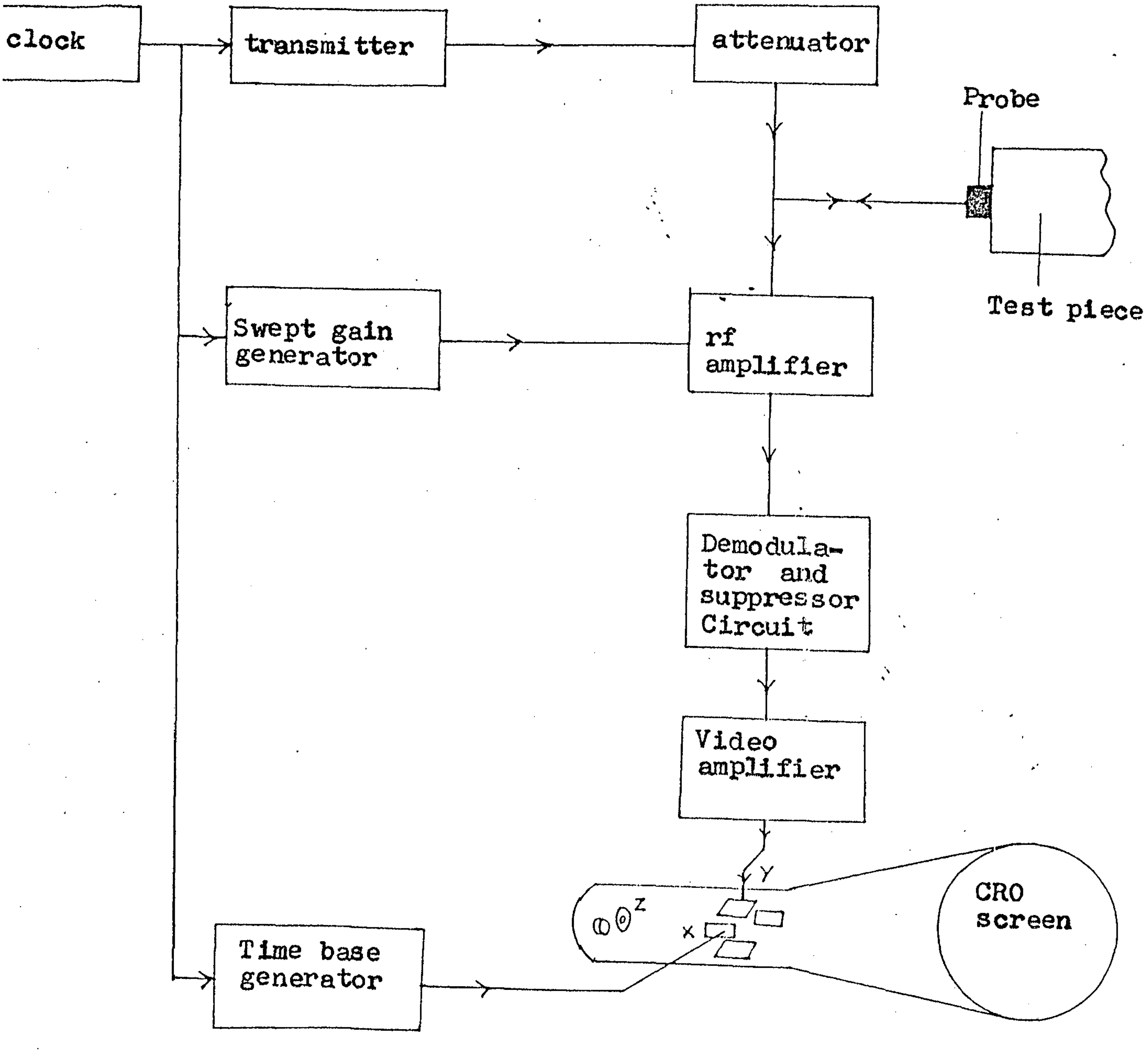


Fig. 3.13 Typical pulse echo system. The block diagram shows an A-scan with the probe in contact with the test piece.

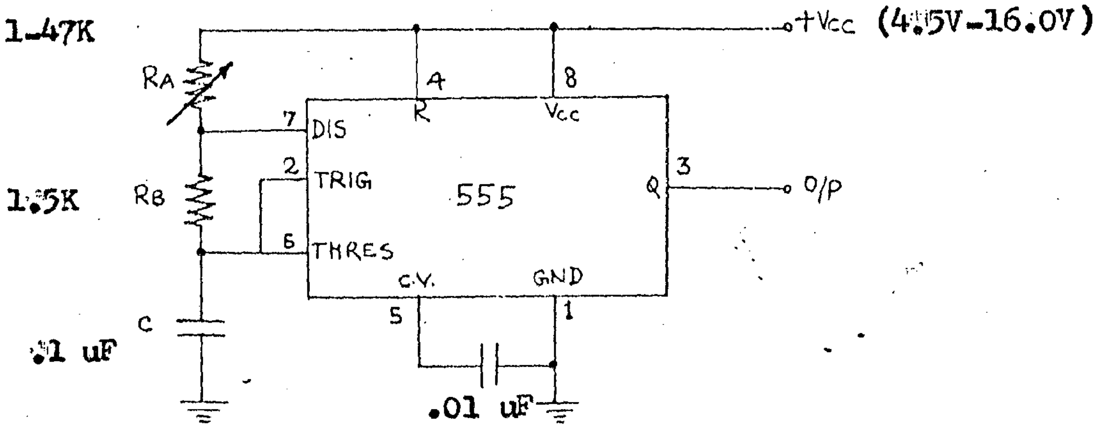


Fig.3.14 Clock circuit.

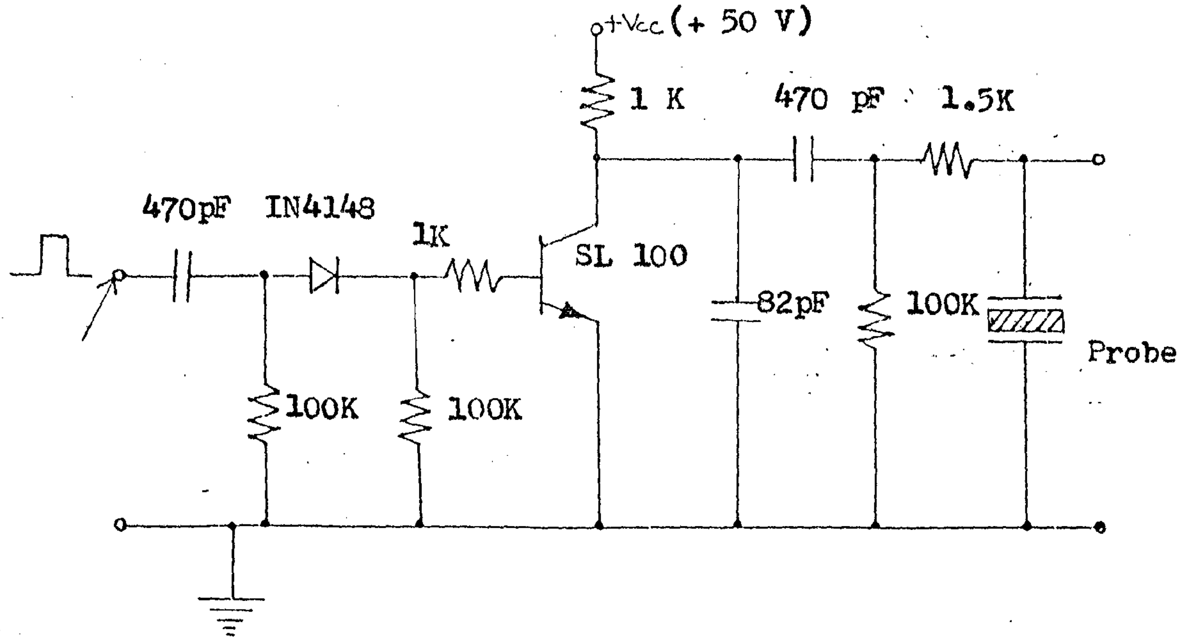


Fig. 3.15 Transmitter Circuit.

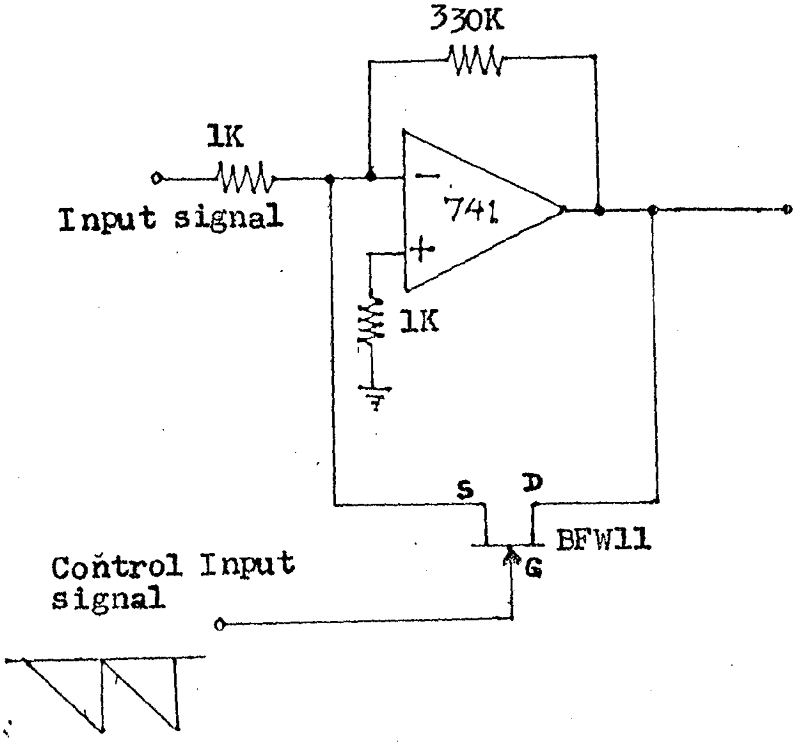


Fig. 3.16 Swept gain control circuit

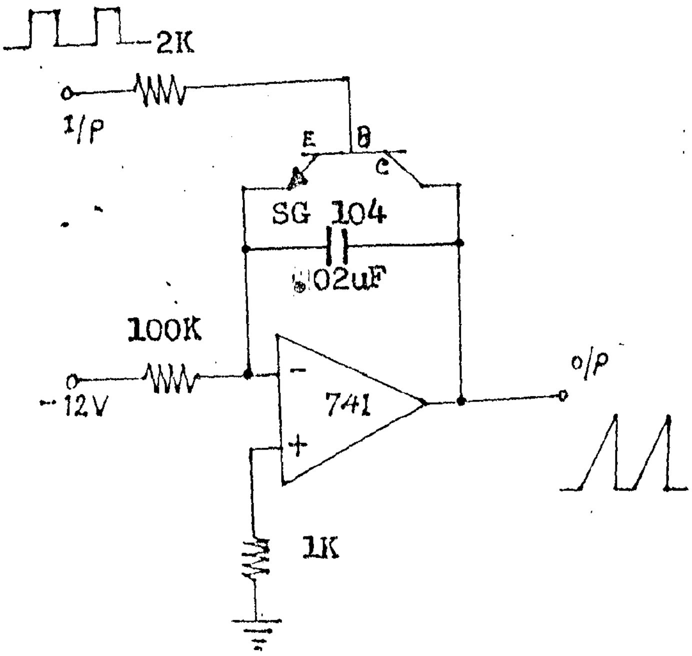


Fig. 3.17 Time base generator.

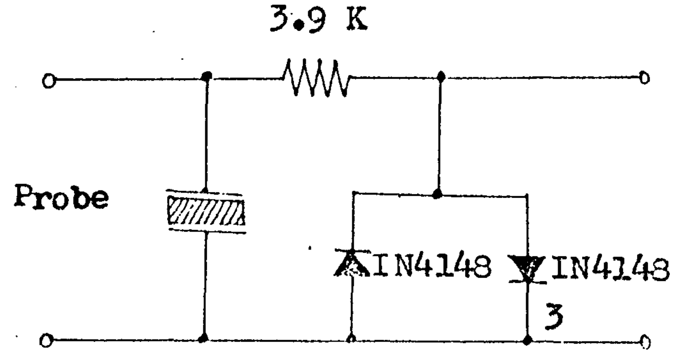


Fig. 3.18 Protection circuit

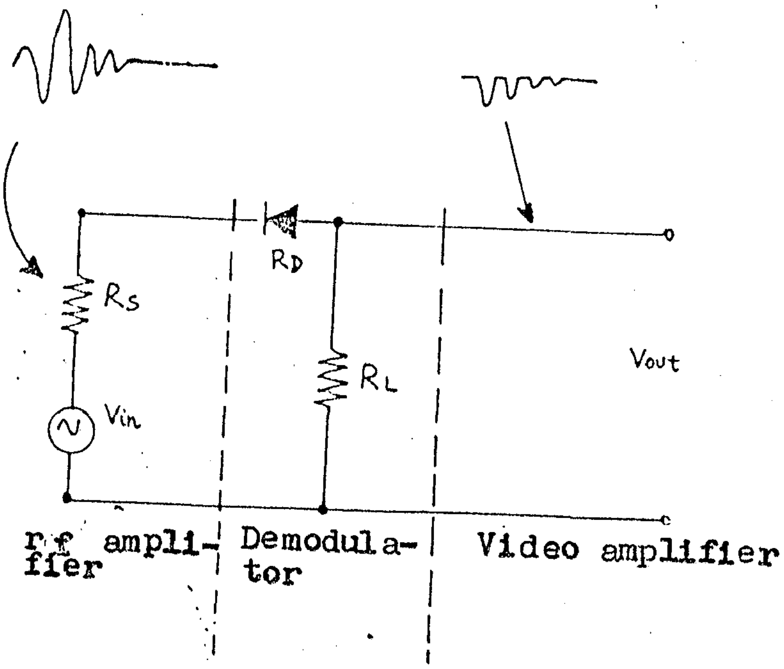
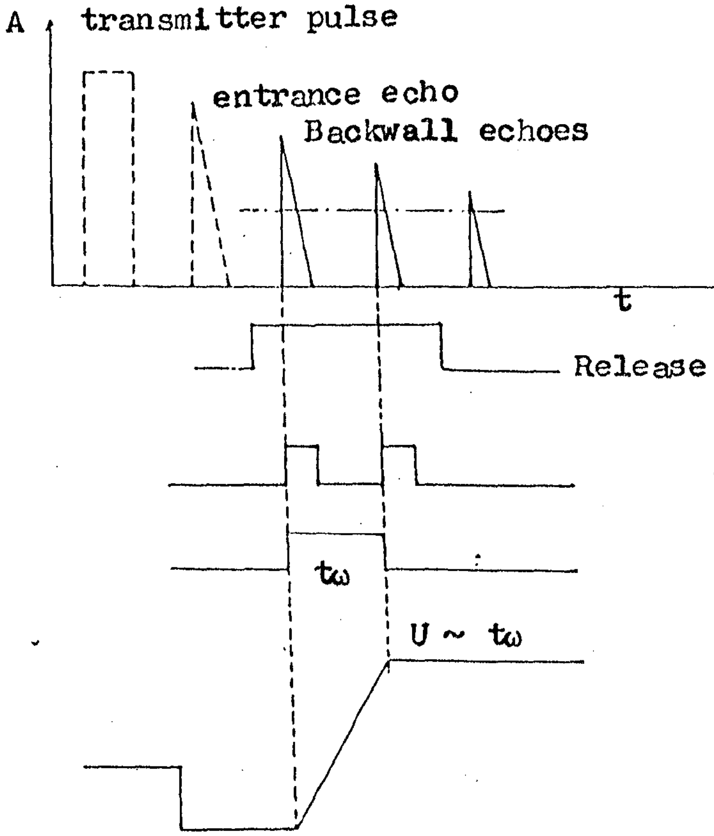
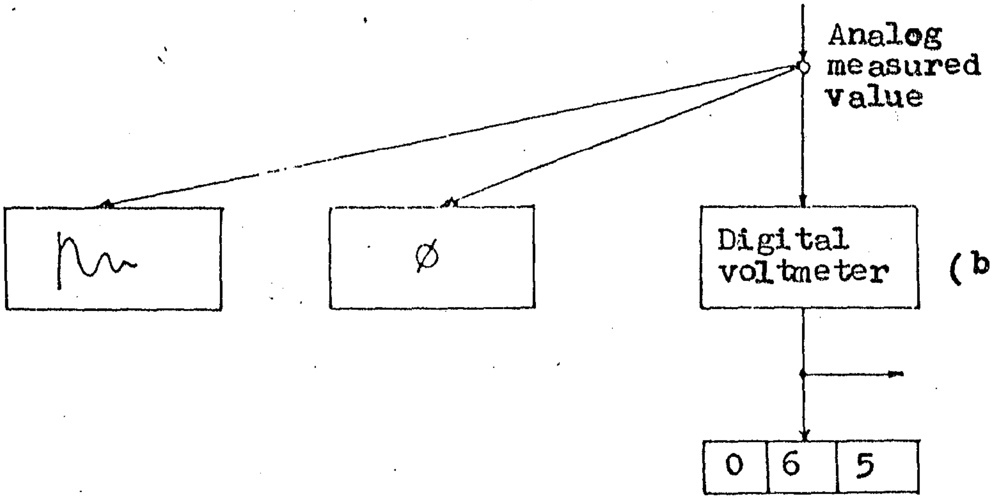


Fig. 3.19 Circuit diagram of halfwave demodulation with negative-going video output

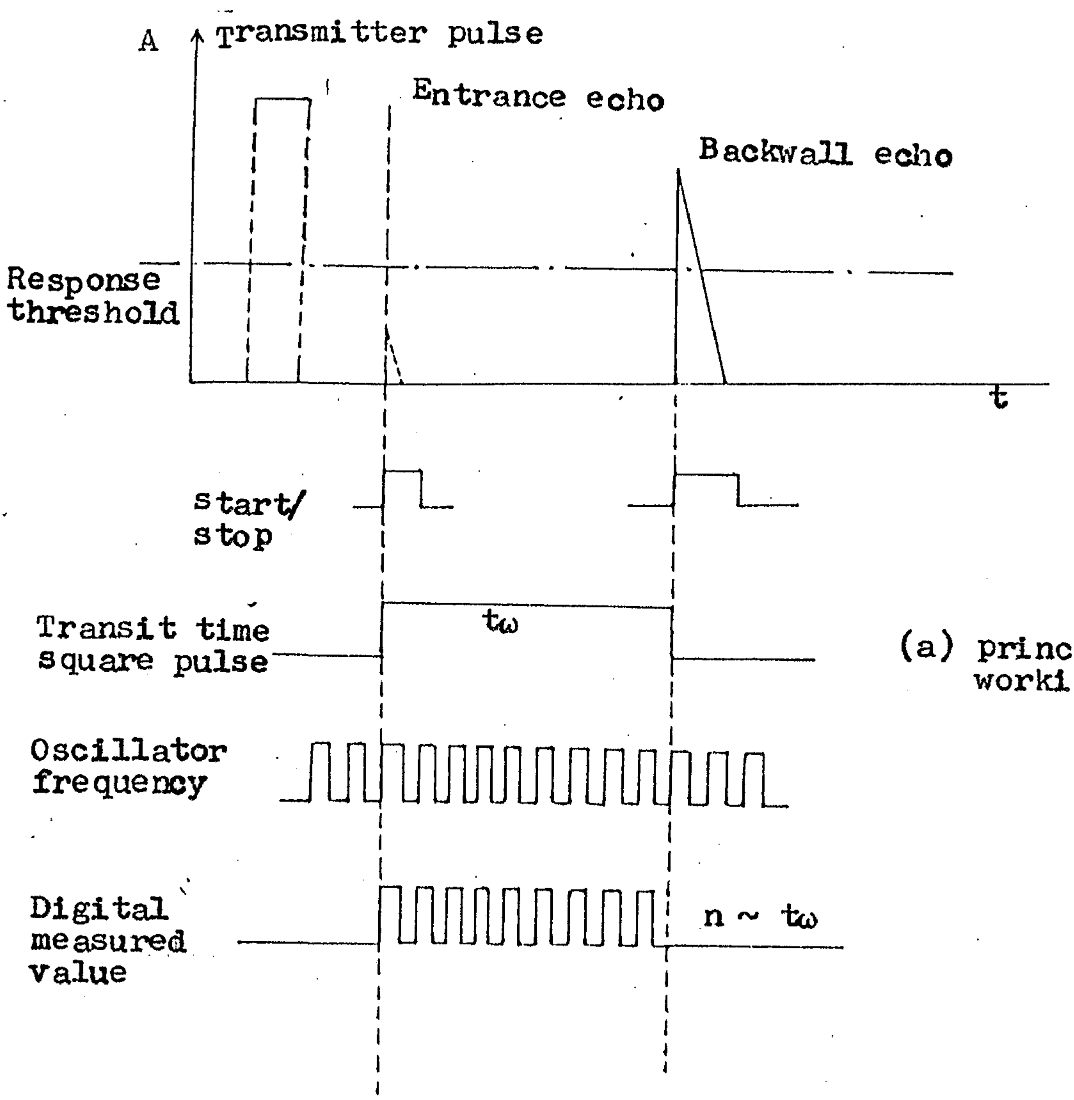


(a) principle and working

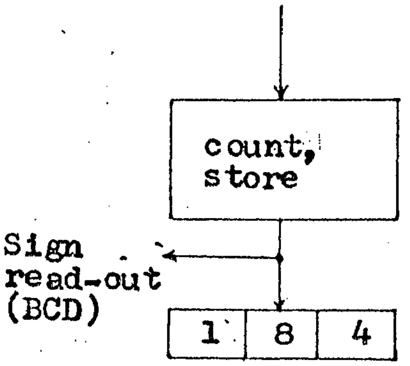


(b) Block Diagram

Fig. 3.20 Integration method with back wall echo pair received with normal probe.



(a) principle and working



(b) Block diagram

Fig. 3.21 Counting method with artificial starting pulse and one backwall echo received with TR probe.

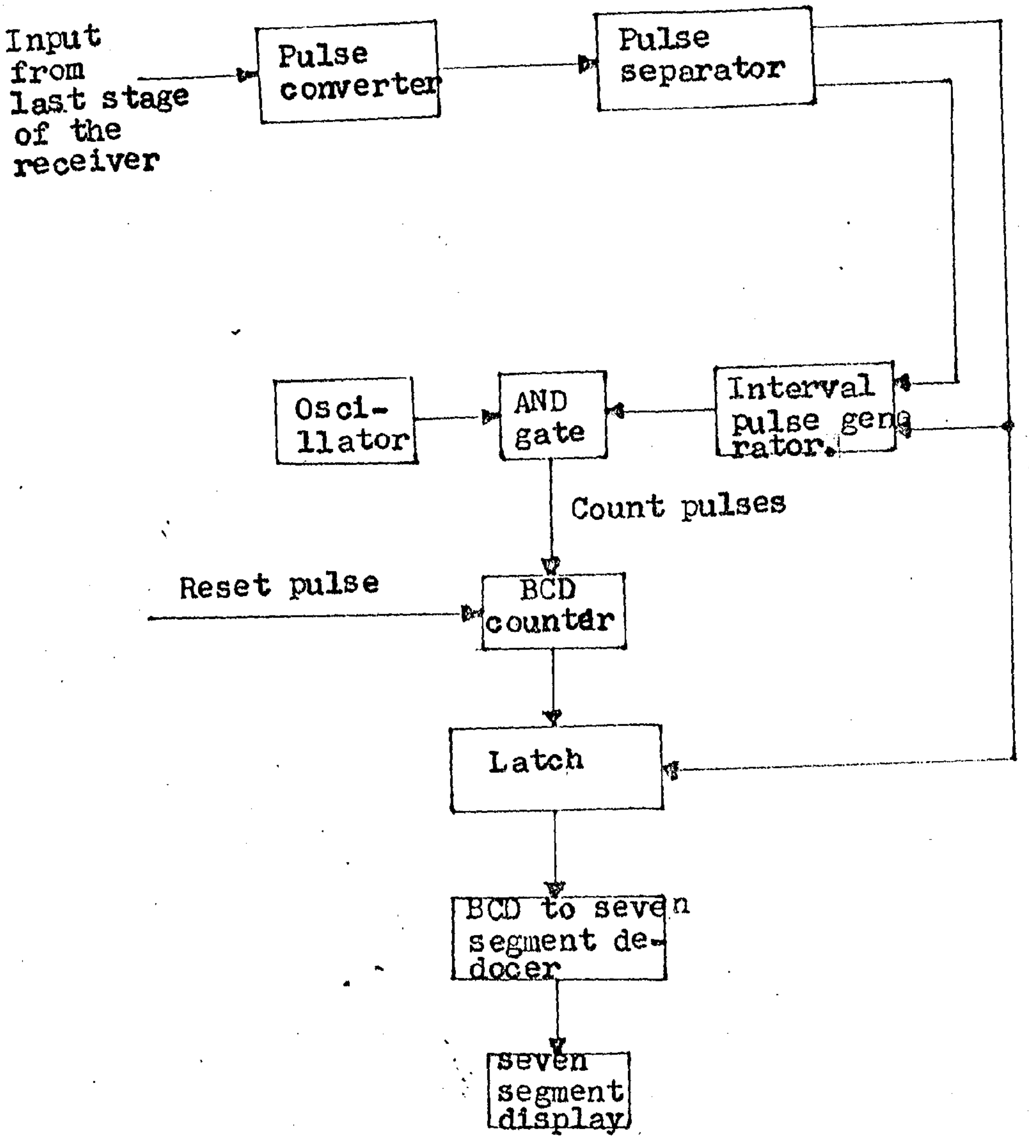
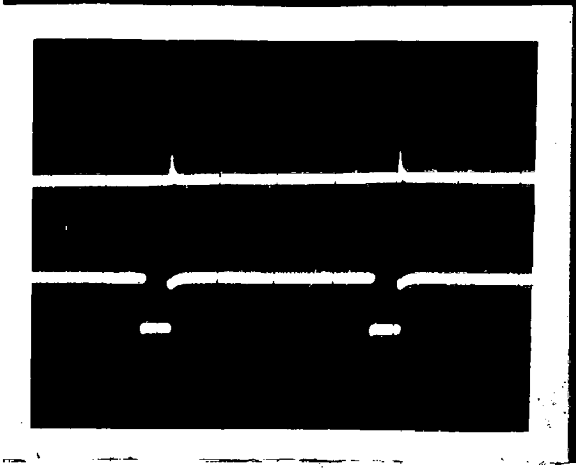


Fig. 3.22 Complete schematic of digital readout for the developed system.

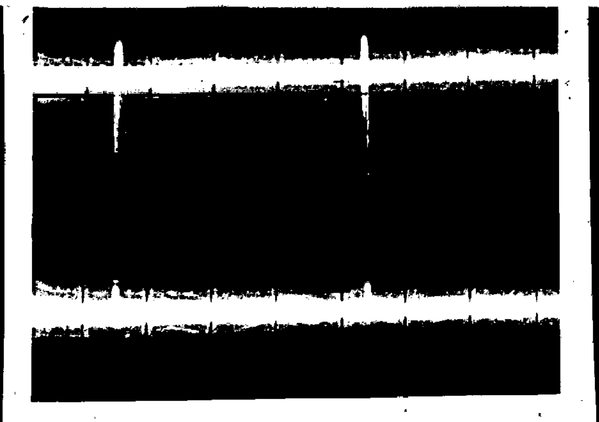


P1 (a) Differentiated input fed to the transmitter.

(b) Clock output from 555 timer

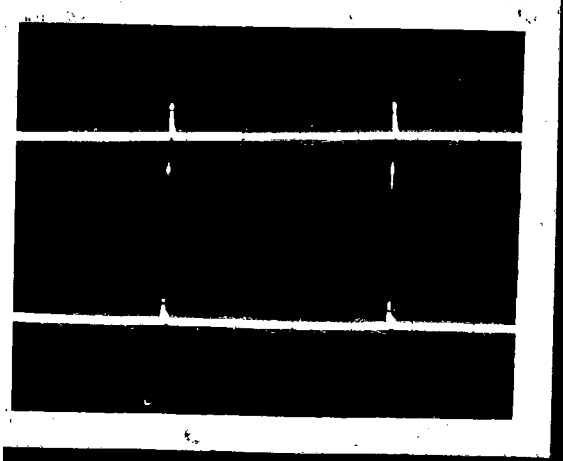
P2 (a) Transmitter output (probe unconnected).

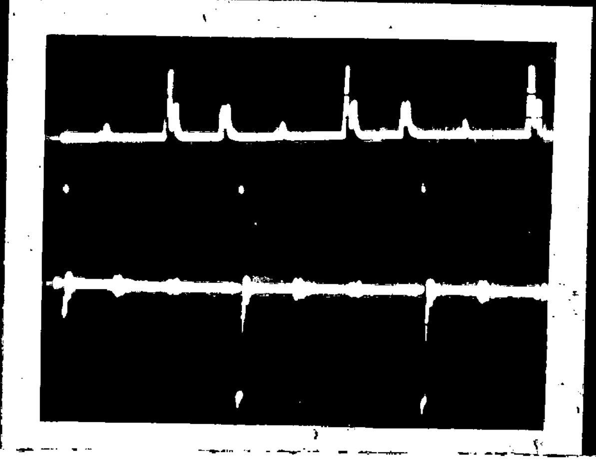
(b) Differentiated input fed to the transmitter.



P3 (a) Transmitter output (probe connected).

(b) Differentiated input fed to the transmitter.



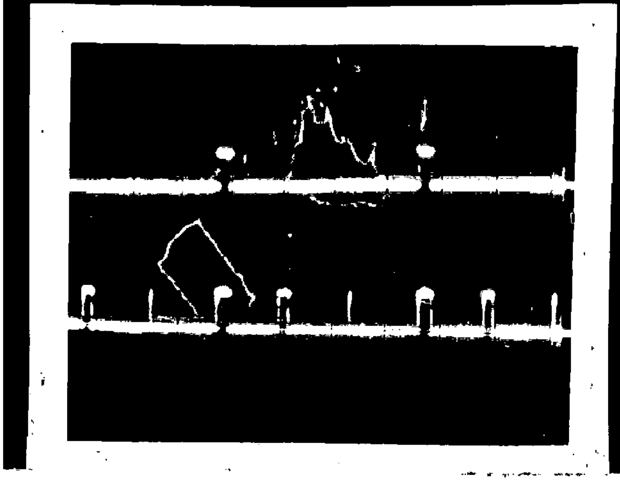


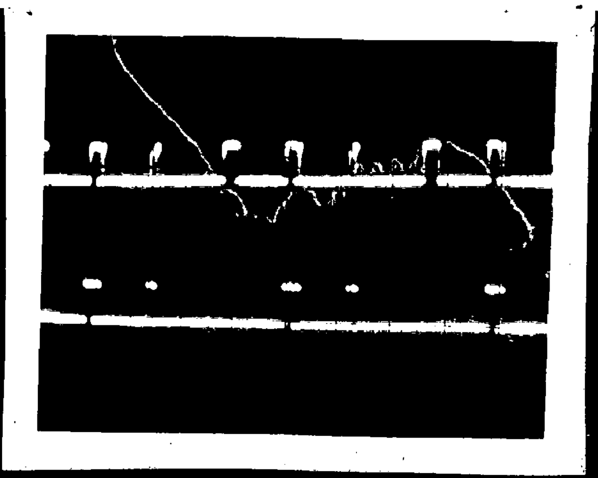
P4 (a) Output at last stage of the video amplifier (final output:received echoes clearly observable)

(b) Output at rf amplifier stage (received echoes clearly observable but signal is demodulated).

P6 (a) Signal consisting of transmitted and received echo pulses.

(b) EX-ORed output (only received echo pulses)



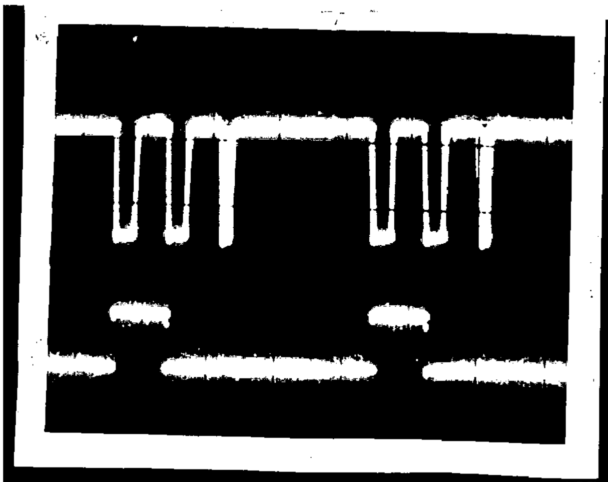


5 (a) ANDed output (only transmitted pulse).

(b) Logic inverted output (Signal consists of transmitted and received both pulses).

7 (a) Signal consisting of transmitted and received echo pulses.

(b) Transit time interval pulse for first return echo (flaw at 70 cm).

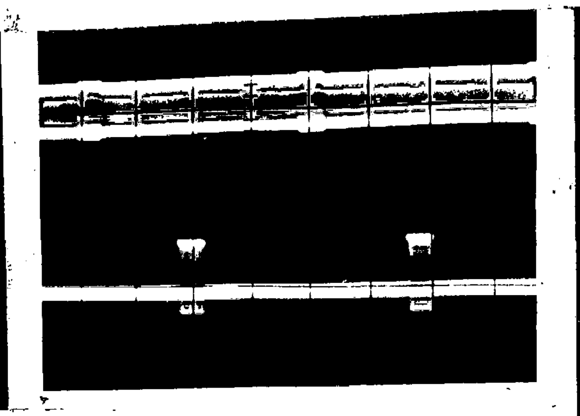


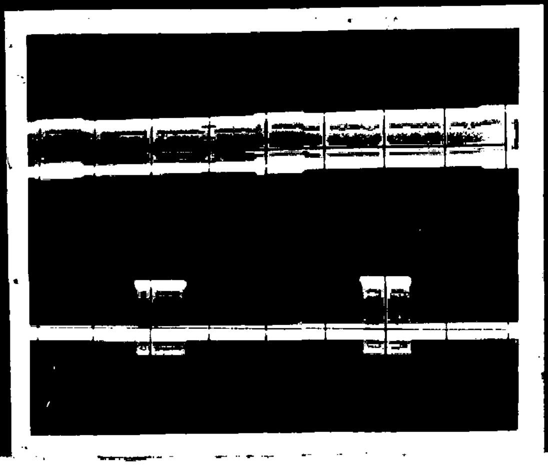
P8 (a) Signal consisting of transmitted and received echo pulses.

(b) Transit time interval pulse for first return echo (flaw at 35 cm).

P10 (a) Continuous high frequency clock signal fed to the counter.

(b) High frequency clock signal for transit time interval (flaw at 35 cm).

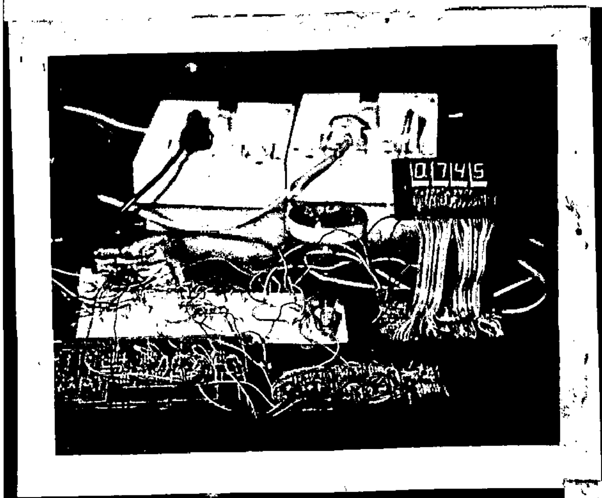


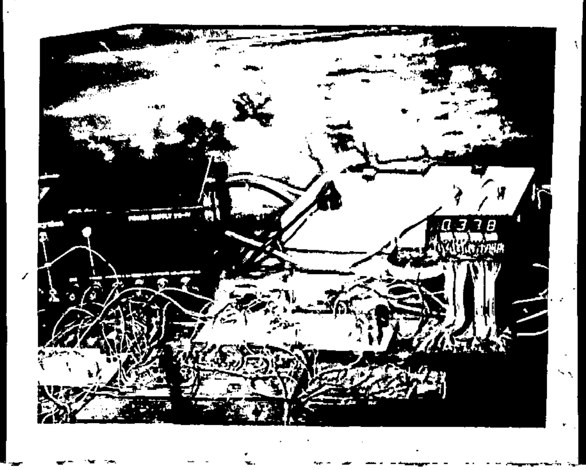


P9 (a) Continuous high frequency clock signal fed to the counter.

(b) High frequency clock-signal only for transit time interval (flaw at 70 cm)

P11 Digital display (flaw at 70 cm)





P12 Digital display (flaw at 35 cm)

CHAPTER -4

REAL TIME ULTRASONIC IMAGING SYSTEMS (PART-II)

4.1 INTRODUCTION

The B-scan presents a crude picture of the structure, within the material, under test. Due to the mechanical movements involved and problem in transducer contact to material pieces, it has almost become out of use in the NDT applications. In contrast, it has emerged as a very powerful method for medical diagnosis [16]. In many ways, it is complementary to X-ray techniques. It enables the characterisation of a plane in the body by receiving echoes from soft tissues. The picture is built upon the CRO screen as the head of the testing probe moves around a section of the patient's body. The procedure is painless. The ultrasound is also thought to be a method which has none of the hazardous effects that are caused by exposure to X-rays.

4.2 DEVELOPMENT OF ULTRASONIC IMAGING SYSTEMS

With the invent of early real time ultrasonic imaging by S.Sokolov and R Pohlman, in late thirties and early fourties, the pulse echo method found its wide application only in 1942, when introduced by F.A. Firestone. Till the present time, the developed accoustical imaging systems fall under three categories [6]. It is also to note that such system also exists which are difficult to be classified under a particular category.

4.2.1 INTENSITY MAPPING ORTHOGRAPHIC SYSTEMS

These systems essentially, produce a two dimensional map of the transmission of sound through an object. The sound is transmitted through the one side of the object while its intensity on the other side is measured as a function of lateral position (fig.4.1). The resulting intensity map is the image. Scanning acoustic microscope (SAM), developed at Stanford University by C.F.Quate and colleagues, is a successful modern realisation of such a concept. The concept is similiar to scanning electron microscope. It is the result of the painstaking research of twenty years, which produced a perfect SAM and made it a commercially available instrument.

4.2.2 PULSE-ECHO SYSTEMS

Ultrasonic flaw detectors for weld inspection in piping and nuclear plant containment vessels are well known instruments based on the pulse echo method. Clinical application of this method includes B-scan. B-scan methods convert the echoes scattered by tissues in the body into two-dimensional slice images similar to tomograms, in appearance. Some times, a phased array is used for electronically focussing and scanning of an ultrasonic beam. During this, the point on a television screen which corresponds to a location of the scattering point in the body, is matched with the return echo. The array itself provides the matching. As a result, a two dimensional image is seen on the TV screen.

4.2.3 PHASE AMPLITUDE APPROACHES

These systems are based on Sokolov's ideas, Some of these systems work in the same way as Sokolov's liquid surface imaging systems do. The main competitor to the Scanning acoustic microscope (SAM) is a scanning laser acoustic microscope (SLAM) [17]. The SLAM is a juiced-up version of Sokolov's original concept and it produces a real-time display on TV screen. Other holographic approaches make use of transducer arrays. These also, incorporate fast fourier transform (FFT) signal processing to produce images and hybrid pulse-echo and holographic techniques. At a final point, holographic imaging combined with multiple projections produces acoustical tomography. Acoustical tomography forms the 'ultimate' in data acquisition and signal processing complexity for acoustical imaging.

As the present system, developed here, is based on pulse-echo technique, only concerned various schemes and some specific features of them will be taken up to have a concrete view on the system.

4.3 PULSE ECHO METHOD IN ULTRASONIC IMAGING SYSTEMS:(B-SCAN)

Ultrasonic images can be divided into two rather broad categories; 'B-scan' images and 'C-scan' images. Each of these can be further divided and subdivided into some other classifications. These classifications are based on scan technique (phased array, electronically stepped array, or mechanical) or scan type (linear, sector, arc or compound). In general, each scan technique has a full range of scan modalities. The situation becomes more complicated, when we talk of real-time or non-real time scanners, 'waterpath' or 'contact' scanners and reflection (pulse-echo method) or 'transmission' (intensity method) modes.

The present work is only limited to B-scan reflection mode. The principle and its instrumentation follows in the coming sections.

4.3.1 WORKING PRINCIPLE AND BLOCK DIAGRAM

B-scanning, or brightness-mode scanning, provides a two dimensional cross sectional reflection image of the object that is scanned. A B-scan image is formed by sweeping a narrow acoustic beam through a plane and positioning the received echoes on a display, such that there is always a relationship between the display scan line and the direction of acoustic propagation in the test specimen. Generally, the same transducer is used to send and receive the acoustic signals. One dimension of the image is inferred from the arrival time of the reflected echoes of short acoustic pulses. Signals, received from structures close to the transducer, arrive earlier than signals from farther locations. The other (transverse) dimension is obtained by moving the transducer (either physically by mechanical means or apparently by electronic means) so that a different straight line path through the object is examined by another short acoustic pulse. This process is continued till the scanning of the entire region of interest is carried out. Some means of tracking the propagation path through the object is required in order to clearly identify the image.

Fig. 4.2 shows a block diagram of a generalised B-scanner. An electronic pulser excites the transducer and in consequence, a short burst of ultrasound is generated. Acoustic signals, reflected from objects in the acoustic path, impinge on the transducer. These are now converted to electronic signals and processed for display. Some times, a swept gain is provided to partially compensate for the attenuation experienced by signals reflected from the deeper structures. The position and angular direction of the beam are determined by position monitoring electronics which accounts for the image signals. As the echoes are received by the transducer, they are amplified, rectified and filtered. The resulting signal is used to brightness modulate the display.

4.3.2 SCANNING METHODS

There are three scan modalities as linear, sector and arc. Typically, the transducer diameter is kept to a very small fraction of the scanned dimension. The combination of one scan modality with other produces a compound scan. Brief description of each modalities follows as under:

4.3.2.1 Linear Scan

In a linear scan, the transducer moves in a straight line (fig. 4.3a). The length of travel of the transducer here, decides the field of view. However, in the time (or depth) dimension, the field of view is limited only by the depth of penetration (i.e. the frequency and attenuation) or the physical size of the object, being scanned. One advantage of this technique, is that the image may consist of a uniform line density, which results in constant spatial sampling rate of the object and a pleasing display on the monitor.

4.3.2.2 Sector Scan

In the sector scan, the transducer position remains fixed at a point on or above the object. Transducer, here, is moved through an angular sector (Fig.4.2b). In this case, the field of view increases with depth of penetration. However, the line density decreases as the field of view expands. This type of scan is particularly well suited for imaging through narrow apertures, such as, for imaging the heart through the ribs.

4.3.2.3 Arc Scan

In an arc scan, transducer is moved along the arc of a circle (fig. 4.3c). It gives rise to an image format which is the inverse of the sector scan. The field of view here, is largest near the transducer and decreases as the depth of penetration increases. The arc scan (or a close approximation to it) is most often encountered in manual scans of the abdomen, the surface of which resembles the arc of a circle.

4.3.2.4 Compound Scan

The compound scan is a combination of the sector scan with either a linear scan (fig.4.4) or an arc scan. The compound scanning is used to overcome a major problem in B-scan imaging, namely, the difficulty of imaging specular reflectors and objects lying behind specular reflectors. The parts of the specular surface,missed in simple scan, are also imaged by the compound scan.Compound scan is also useful for imaging behind highly reflecting or attenuating structures (e.g. ribs) since hidden object points can be imaged from an unobstructed direction.

Each of the basic modalities can involve manual, automatic mechanical, automatic electronic and hybrid combinations. Some of these techniques can be utilised for real time imaging. Thus, they are capable of acquiring and displaying dynamic images of test piece that are in motion.

4.3.3 TYPES OF SCANNERS

Another distination, often applied to the general B-scan category, is whether a system is a contact scanner or a water path scanner [18]. In the former the test piece is in direct contact with the transducer while in the latter the water serves as the coupling media and thus, the sound beam passes through the water before entering the test piece. The water path scanning technique is used principally, in automatic mechanical scanners to isolate the mechanical motion from the test specimen. Usually, the water path distance is made somewhat larger than the desired depth of penetration. This is so done to estimate artifacts that may, otherwise, appear due to reverberation between the material and the transducer.

In reference to the present work, the instrumentation of only contact scanners are discussed. The B-scan mechanism is mainly used for medical diagnosis but for some specific industrial applications, it has a great deal importance.

To produce a B-scan image, some means for moving the ultrasonic beam is needed. Many currently available, contact B-scan instruments utilise some form of mechanical systems for moving the ultrasonic transducer and thus, the ultrasonic beam. On the basis of their moving mechanism, these are categorised in two types as manual or motorised movement. The same effect is obtained by electronically switching or 'phasing' stationary transducer elements of an ultrasonic array. Two methods of array scanning have been realised in diagnostic instrumentation (Also, can be employed for industrial applications); the 'linear stepped array' and the 'linear phased array'. In all cases, these systems employ transducers in direct contact with the surface of the test piece (or skin of the patient).

4.3.3.1 MANUAL SYSTEMS

The manual compound contact B-scan system, has been the backbone of diagnostic ultrasound imaging for many years. This form of ultrasound imaging system led to the development of equipments capable of producing images with a significant degree of diagnostic information.

Contact B-scan imaging system consists, basically of three parts: 1) a scanning arm to control the travel of an ultrasonic transducer to maintain the ultrasound beam in a single plane, 2) appropriate electronics for amplifying and detecting the returning echoes, monitoring the position and angle of the transducer and driving and deflecting a display device; and 3) a display device to convert the electronic signals into an image on a CRT device. A typical B-scan manual system's schematic is shown in fig. 4.5.

One of the limitations of this technique is that image quality can be affected by the manner in which the scanning is performed. Therefore, ultrasound technologists must be trained to develop a good scanning method.

4.3.3.2 Real time system

Instruments, which can produce images rapidly enough to display the movement of various portions of a scanning piece, are called real-time systems. In case of medical diagnosis, it has an added advantage. Since the operator has nearly instantaneous feedback, patient's procedures can be accomplished very rapidly as a little time is wasted in locating the organ or tissue of interest. In real time systems, the ultrasonic beam is scaned either mechanically or electronically.

(a) Mechanical Scan

There are many types of real-time imaging systems, currently in use. The simplest technique is to replace human hand with a mechanical system that moves the transducer automatically. One such system is the mechanical sector scanner.

In the system, a motorised mechanism moves the transducer automatically. In the process, the transducer is kept in proper contact with the test piece. Position sensors continuously deflect the angle of the transducer and produce a signal corresponding to the position of the displayed echoes in the image. No scan arm is needed here. In other respects, it resembles with the manual B-scanner.

(b) Electronic Scan

There are two distinctly, different- types of electronically scanned, contact B-scan imaging systems: the linear stepped array (commonly called the 'linear array') and the linear phased array (commonly called the 'phased array').

The linear array requires a large number of small rail road- tieshaped transducer 'elements'. These are arranged next to each other so as to form a line array, usually about 1 cm wide and 10 to 15-cm long. A typical linear stepped array configuration is shown in fig. 4.6a. One to four transducer elements are activated at a time and are sequentially stepped along the array so that the ultrasound beam is moved in a linear path while keeping the array stationary.

The phased array [19] has a similar constructions but differs in operation. A phased array transducer is smaller (about 1-cm across and 1-to 3-cm long) and usually, contains fewer elements as shown in fig. 4.6b. All the elements are made active at the same time and the ultrasound beam angle is altered by proper phasing of the signals (going to the elements for transmit) and also by proper phasing of the received signals from each element. This system is analogous to a phased array radar.

4.3.4 SYSTEM CONSIDERATIONS

In chapter 3, the basic block diagram for pulse-echo system have been given. In addition, the design aspects for each block were also discussed. Therefore, the present section is confined only to the various hardware parts, essential for the development of B-scan imaging systems.

4.3.4.1 Transducer

The transducer is the heart of any ultrasound imaging system. It performs the conversion of electrical energy into mechanical energy and also the reverse i.e. the conversion of mechanical energy into electrical energy. There is fundamental relationship between the properties of the ultrasound beam generated by the transducer and the quality of the resulting image.

The transducer design has passed through the stages of steady progress and refinement during the past three decades. The early imaging was performed with single element, unfocussed transducers. The development of focussed transducer is credited to the pioneer work of Labaw, O'Neil and Kossoff.

One of the imaging objectives is to provide the narrowest beam possible while maintaining sufficient sensitivity to penetrate the desired depth of material under test. The consideration is given to acoustic properties of the test material (velocity, attenuation etc.), the required depth of penetration, the speed of image formation, the desired resolution, and the physical restrictions on transducer size and shape. After the selection of a suitable imaging technique, the compromise is sought to achieve adequate spatial resolution and beam properties.

The selection of pulse frequency and bandwidth poses another difficult problem to the transducer design. Three important factors affect the choice of frequency: 1) ultrasonic beam attenuation through the material under test; 2) required depth of penetration; and 3) system dynamic range. To approach a optimum frequency, no strict rule exists for deciding these above variables. Generally, the highest frequency, that provides adequate penetration, is selected.

The performance of a pulse - echo ultrasound system is much more dependent on the characteristic of the transducer. The temporal response i.e. frequency, pulse width and sensitivity is determined primarily, by electro **chemical** properties. However, the spatial resolution is decided by the transducer geometry combined with the frequency and band width. The design of ultrasound transducers thus requires a careful **attention** to several delicate physical compromises [20].

Basic assembly of a piezoelectric transducer is shown in Fig. 4.7.

4.3.4.2 Processing Units

A careful attention is paid to **the design of remaining** part of the front end: the transmitter, the receiver and the analog-to-digital converter or other digital devices. This is so needed to maximise the information transfer from the transducer to the digital processing system. The subsystems, described above, must match the performance characteristics of transducer and the digital system.

(a) The Transmitter

Typical transmitters fall into two basic categories: the pulse type and burst type. The former uses a single electrical spike or pulse in order to minimise the time duration of the transmitted ultrasonic pulses. The latter produces a gated sinusoid or square wave in order to narrow the spectrum of the transmitted ultrasonic wave.

Pulse- type transmitters work by 'shock-exciting' the transducer. These transmitters deliver a short high-voltage unipolar pulse to the transducer, which now resonates to its fundamental frequency. Usually, these transmitters rapidly discharge a capacitor across the transducer with the use of an electronic switch. The turn on time is quite fast (in the order of 1 to 10 ns) and depends on the switching device, used. These devices may be silicon control rectifiers or avalanche transistors. A thorough and comparative analysis of these switching devices produces that FETs including HEXFETs and VMOS devices are best for most of the ultrasonic applications. These devices have fast switching time (10 ns)and low 'on' resistance (approx. 5 ohms).

The second group of transmitters (e.g. burst type) use a number of cycles of a square wave or a sinusoid modulated wave by a Hanning- type window. Square wave excitation is in frequent use as it requires only a simple switching circuit. The use of time or square wave bursts provides a precise control of the frequency spectrum of the energy,transmitted. This has a great usefulness in multiple frequency image processing techniques for speckle reduction. Burst type of transmitters are generally used in phase array transducers, where they improve the signal-to-noise ratio during coherent signal summation.

A recently suggested transmitter circuit uses a digital to analog converter (DAC) to configure the transmit burst under computer control. In this way, any number of relatively complex voltage wave forms can be generated to excite the transducer within the limitations caused by the conversion speed and bit resolution of the converter [21].

(b) The Receiver

The primary purpose of the receiver is to amplify the signals from the transducer, generated by returing echoes within the examined structure. During the process, it must not compromise the frequency or signal-to-noise characteristics of the transducer.

The matching of the receiver with the transducer is the first inevitable fact needed to optimise the overall signal-to-noise ratio and sensitivity. Typical transducers for medical imaging have noise levels approximately 1 µv and voltage levels (on receive) in the order of 10 µv. Received echo signal depends upon the excitation voltage and the sensitivity of the transducer (expressed as a two way insertion loss, typically 140 dB). In addition, it depends on the losses in the medium due to attenuation and reflection at material discontinuities. The maximum SNR is achieved when the transducer and receiver impedences are matched and both the electrical and mechanical resonance coincide.

In case, a single transducer is used for both transmission and reception, the receiver is overloaded during the transmitted burst. This problem is usually, overcome by a resistor in series with a diode clipper as shown in fig. 4.8 and termed as protection circuit in fig. 3.18. However, complicacy in the electrical matching arises due to this protecting resistor. It is chosen so small as to minimise loss and excess noise while receiving.

The most important function of the receiver is analog signal processing. This processing is performed to complement the image processing taking place in digital form. The analog processing is performed to reduce either the dynamic range or bandwidth requirements of the analog to digital converter. These receivers also, employ time gain compensation circuitary. This circuitary provides for the best possible image quality while maintaining image uniformity.

Signal compression is the another form of processing included in receivers. This is done to compensate the strength of reflected echoes which vary over several orders of magnitude. This is also needed for the suitability of gray scale images on the CRT screens. The compression can also be adjusted and so varied for linear to logarithmic. The receivers also, include envelopes to emphasize the boundaries. These techniques are often used to reduce the bandwidth requirement of the analog-to-digital converter.

The exact nature of the processing, taking place in the receiver, is critical to subsequent digital imaging technique; It is also to note that in medical diagnosis, the acquiring information on acoustical parameters of tissue, in order to distinguish between normal and pathological states requires a detailed knowledge of the receiver signal processing [19].

(c) The Image Storage, Processing and Display Units

The B-scan is normally, displayed in one of the five ways. Four of them use different types of oscilloscopes such as; non-storage, long persistance, long persistence storage and bistable storage. The fifth type uses a scan converter plus TV monitor.

A non-storage oscilloscope is the cheapest method of display but open **shutter** photography must be employed before the image **to** be viewed.

The fluorescent screen may have a long persistence phosphor which continues to glow after the electron beam has moved to a different part of the screen. Different phosphors glow for different lengths of time (upto 10 μs) and view is best **seen** in darkened surroundings. Such a system enables the operator to see the complete B-scan picture without distorting the photography [16].

An oscilloscope (long persistance storage oscilloscope) can be made to store the image for a longer time by incorporating in the system a storage grid of insulated electrodes, a collector grid at about +200V and a source of electrons that can be made to flood the screen completely from a flood gun.

The Bistable storage tube is simpler and cheaper than the variable persistence type. It has no facility for variation in spot size to produce any gray scale. Ultrasound echoes are displayed as very small dots with the same size and brightness.

A cathode ray storage device based on analog scan converter contains a solid state storage surface composed of many small diodes. It also has an electron gun for addressing the diodes and reading the stored data. Being an electron beam device, it offers a great flexibility. The data can be written slowly and read quickly. It thus, allows for a standard television display to be used for producing the image [18][21].

Some modern scanners use a digital (solid state) scan converter [22] made of semiconductor memory integrated circuits working with electronic control circuits. In the digital scan converter, the image is usually broken into a matrix of points or pixels and a memory location is assigned to each pixel. A number corresponding to each pixel is stored in its corresponding location as the scan is being made.

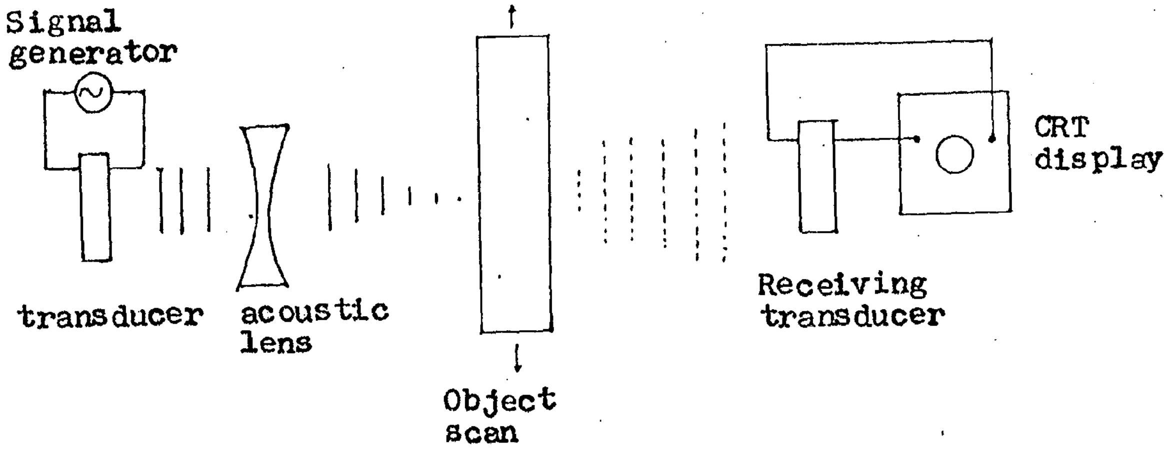


Fig. 4.1 Intensity-mapping concept.

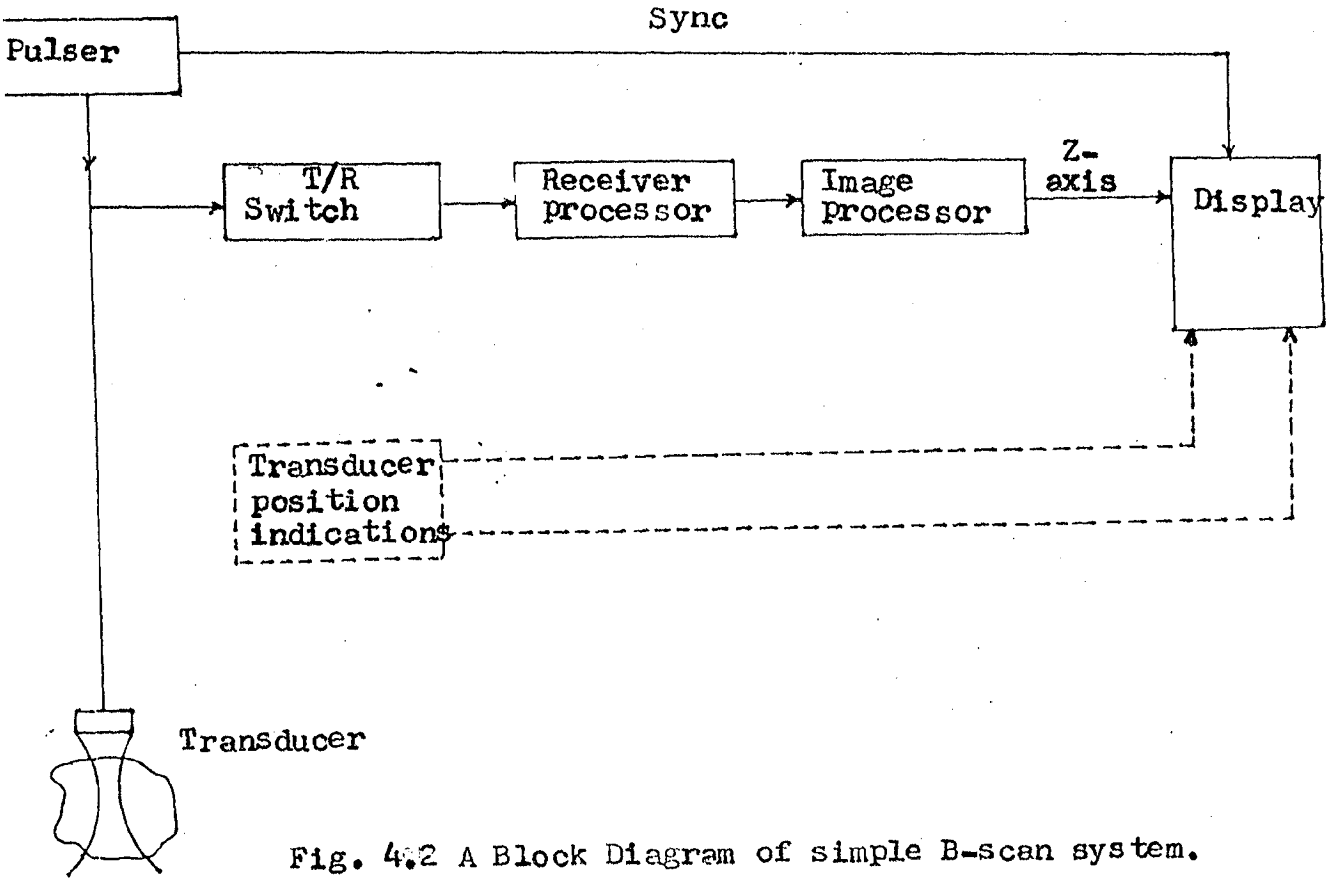


Fig. 4.2 A Block Diagram of simple B-scan system.

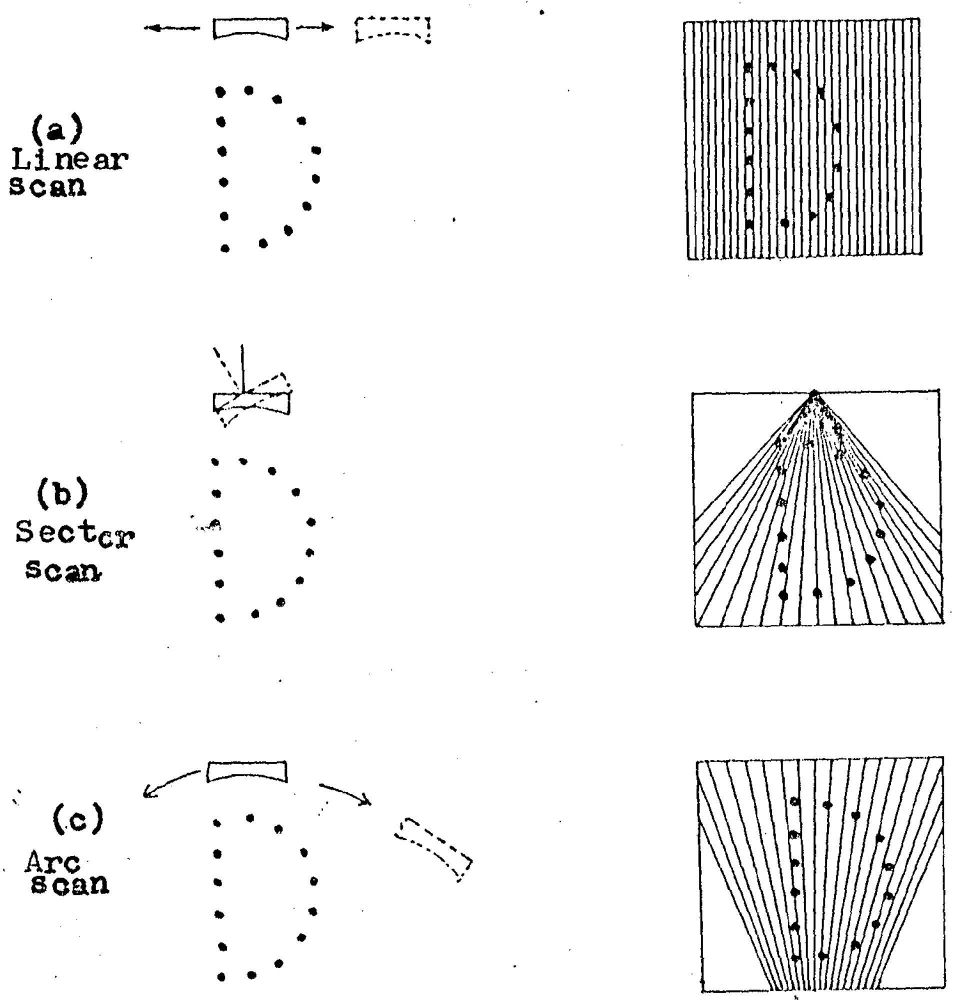


Fig. 4.3 Mechanical motion and image format for (a) linear (b) sector and (c) arc B-scans

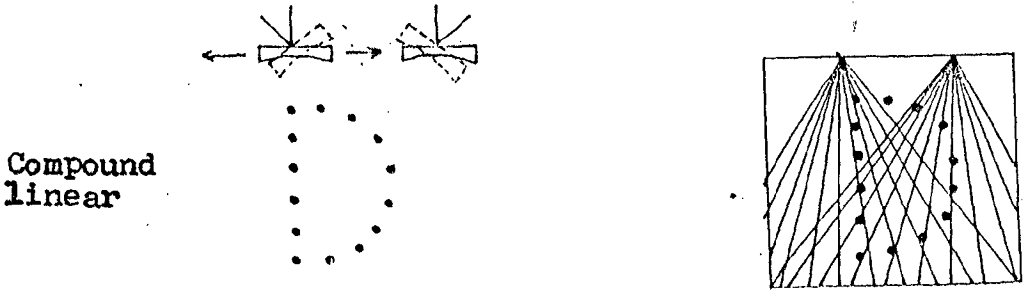


Fig.4.4 Mechanical motion and image format for a compound linear scan (only two positions shown).

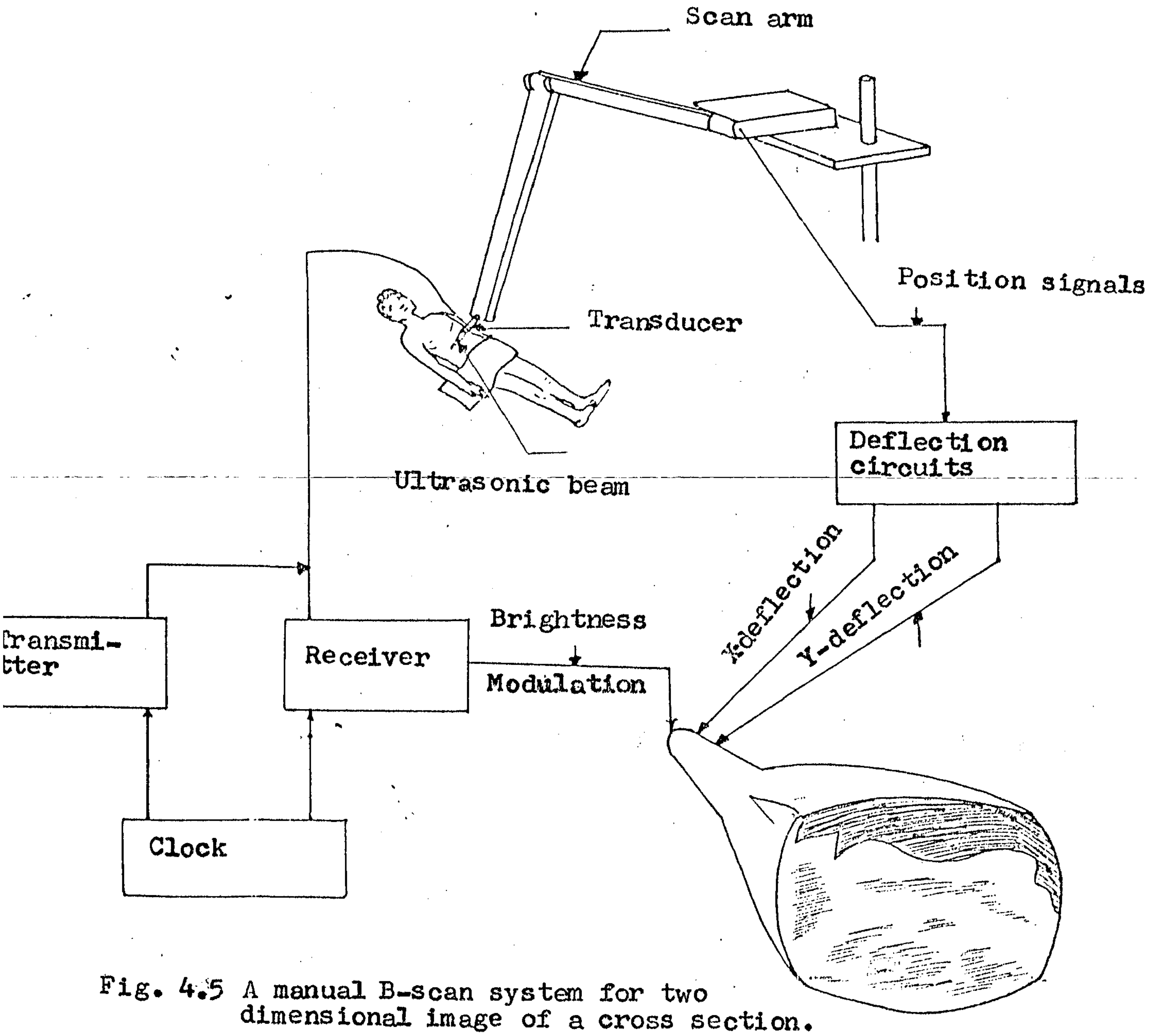
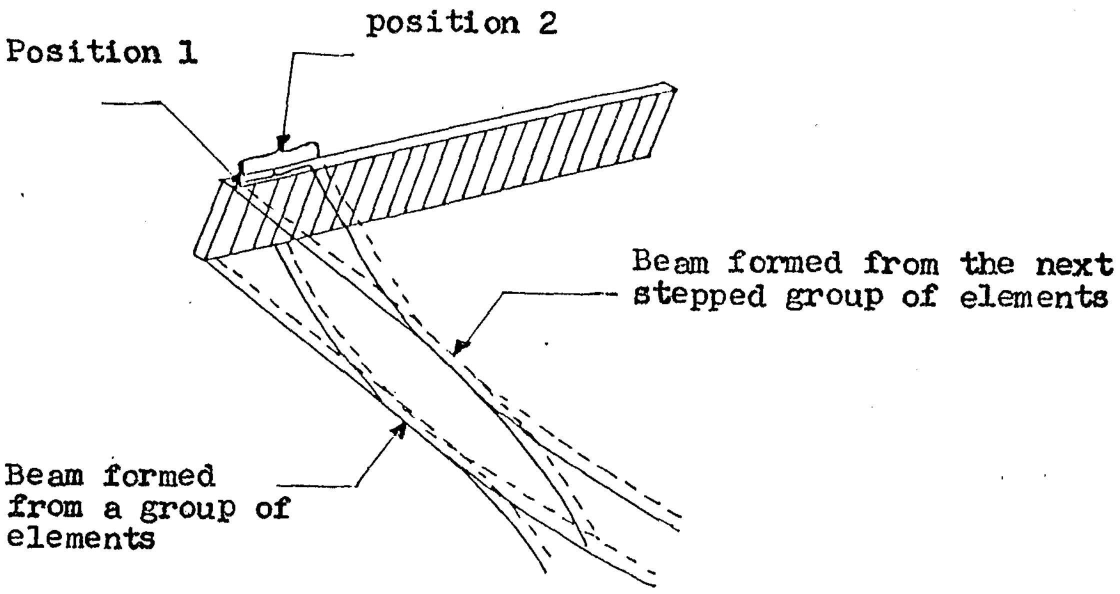
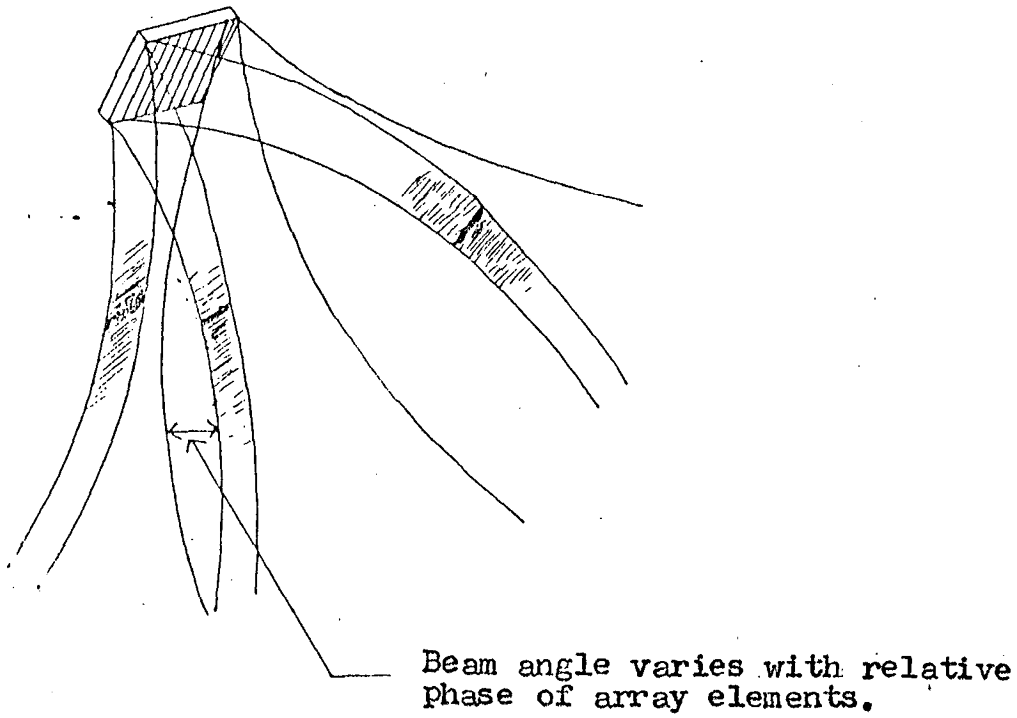


Fig. 4.5 A manual B-scan system for two dimensional image of a cross section.



(a) Linear stepped array system



(b) Linear phased array system

Fig.4.6 Linear array ultrasound scanners.

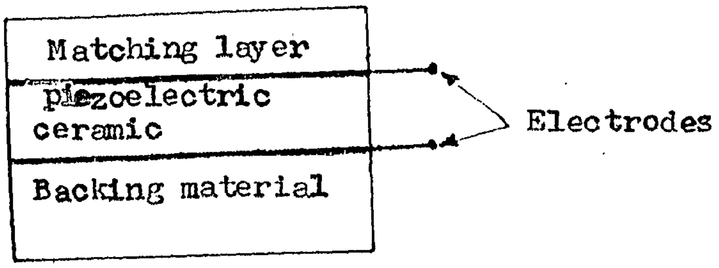


Fig. 4.7 Basic piezoelectric transducer configuration.

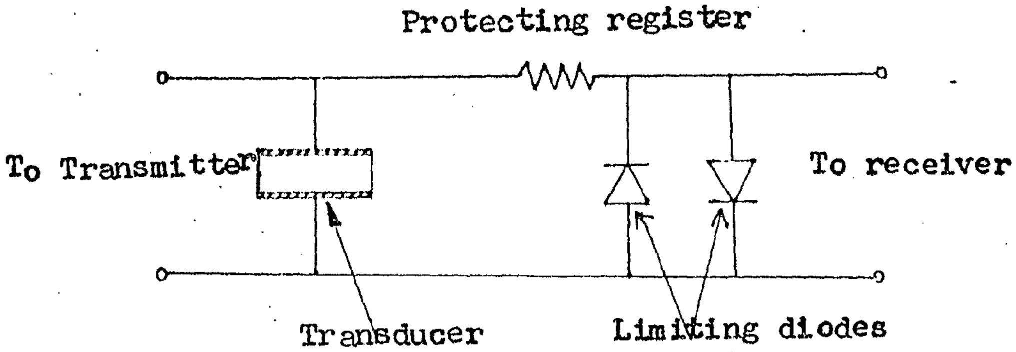


Fig. 4.8 Standard circuit to prevent receiver overload.

CHAPTER - 5

DEVELOPED ULTRASONIC IMAGING SYSTEM

5.1 INTRODUCTION

A fundamental requirement for a technique to prosper is its natural foundation in physical principles that allows it to perform some functions better than other competitive approaches. Acoustical imaging technology suffers a crucial innovation as to fight with other imaging methods and successfully take a lead over them in commercial, industrial, clinical and military applications. The ultrasonic imaging system developed by the author has very useful features so that it can withstand in the crucial field of imaging technology. These features will be overviewed in this chapter after the system details have been discussed.

5.2 BLOCK SCHEMATIC

Block schematic of the imaging system developed here is shown in fig. 5.1. A brief description of its various elements is given in the following paragraphs.

The ultrasonic transducer, used, has a natural frequency of 2.5 MHz and diameter 15 mm. This is a piezoelectric transducer which gets excited through a short burst of electrical pulse. The transmitter incorporates a medium power Bipolar transistor, through which the capacitor voltage is discharged into the transducer capacitance.

The central processing unit (CPU) is a 8-bit microprocessor 8085 [23]. This performs the various functions as pulse generation, pulse reception and the analysis of arrival and generation instants of the pulses. The CPU also, generates the signal for transducer movement and corresponding position signals (x and y coordinates) are stored in the RAM area provided for the purpose. The interval count is stored just after the position signal. The moving device is a mechanical system, configured to produce movements in two directions (x-axis and y-axis) perpendicular to each other. Two Stepper motors are the important components of this mechanical system.

Display device is a non-storage type CRO, which receives signals from three digital to analog converters (DACs), One for each x,y and z axes, fed from the CPU. The analog processing unit consists of amplifiers and demodulator and suppressor circuits. Pulse converter is a circuitary, which converts spike pulses to rectangular pulses. The digital processing unit is a device to generate a pulse of length equal to the interval between transmitted and the first received pulse.

The square waves, generated by μp, are converted into a short electrical pulses of large magnitude, through the transmitter circuit. This pulse excites the transducer so that a short burst of ultrasound is generated. Acoustic signals reflected due to impedence mismatch are impinged on the transducer and converted to electronic signal, which after analog and digital processing, is received by the CPU. The µp continues to count in the interval between transmitted and received echo pulses. The final count is stored as z-coordinate for the z-modulation (i.e. intensity modulation).

As a first step, the scanning mechanism is initialised for the scanning of the test piece. This is the origin of scan and this information is stored as a first position signal. Now, the origin point is interrogated by ultrasonic wave penetration through the piece. The interrogation is done in the above mentioned way.

Now onwards, x and y coordinates are increased according to scan line and subsequently searching is also performed in the above illustrated fashion. The entire process is continued till the desired region is scanned. When the scanning is finished, the stored data is processed and fed for display. The processing involves the conversion of digital signals (stored as x, y and z-coordinates) into appropriate analog signals to produce a good picture on the screen. The display device (i.e. non-storage CRO) requires the signals in analog form. When x and y signals are fed, the spot moves according to these signals, while its intensity is governed by z-modulation, fed as z-coordinate signal. From the CPU, these signals are delivered in the same sequence as stored. When all the data is fed to the CRO, the same data outputting process is repeated, so as to produce a stationary picture on the screen. Through the whole process, a cross sectional view of the test piece, towards the front face is viewed on the screen.

5.3 SOFTWARE

The flowchart for the overall function, i.e. pulse generation, pulse reception and also the reception and storage of transducer position signal along with the controlled movement of scanning mechanism, is shown in fig. 5.2. This is the main software flowchart, which calls for two subroutines: one, for the forward and backward motions of the stepper motors [24] and the other, for searching z-data (fig. 5.3).

The software flowchart for displaying these signals on CRO is given in fig. 5.4.

These flowcharts are briefly explained in the following subsections.

5.3.1 MAIN SOFTWARE FLOWCHART

This flow chart describes the complete operation of the imaging system developed. As a first step, the all ports of 8255, in operation are initialised for their particular configuration. Two 8-bit ports (A,B) of 8255 are made to work as output ports, and feed coded signal to four winding terminals of the two stepper motors (one port for each motor) through the two power modules. The port C of P_1 is configured in both way. Its upper part is configured as output port (fed to the transmitter) while its lower part is opted to work as input port (receiving signals from the digital processing unit).

The interval registers B and C are used to generate the position signals (in actual, they perform the function of counting the steps of movement), accordingly.

The HL pair of registers determines the memory location from where the data storage starts.

After the initialisation of all the registers and parts, the first position signal is generated by selecting the counters B and C, representing x-axis and y-axis coordinates, respectively. This signal is stored in the memory location addressed by the HL pair of registers. Now, the subroutine for z-data search is called and after the execution of this subroutine, the next position signal is generated. It is so done by moving the transducer one step in x-direction while calling the subroutine for its forward motion and increasing the x-axis count in register B. This count is further checked for range coverage. If the range is not covered, the same process of storing position signals and the z-data search is performed by excecuting their corresponding subroutines. The process of position signal generation, its storage and corresponding interrogation (z-data search) is repeated till the coverage of one scan line in-the direction of x-axis.

When the one scan line is covered, the other scan line is sought by the same process. One step movement in y-direction is obtained by calling the subroutine for it.

Different scan lines in x-direction are achieved doing step by step **increment** in the y-axis count. After the coverage of y-axis range the system is resetted to its original point.

5.3.2 FLOW CHART FOR Z-DATA SEARCH

Interrogation at each search point is initiated by generating a clock signal. Its frequency is determined by the depth of penetration. The clock signal is fed to transmitter which via generating a short electrical pulse of large magnitude excites the transducer to generate short burst of acoustic pulses. These acoustic pulses, reflected by impedence discontinuities, **impinge** on the transducer and being converted into electrical pulses and further processed by analog and digital processing units, are fed to the CPU, which accounts for the time interval between transmitted and the first reflected pulse while analysing the instants of transmitted and the reflected pulses. The storage of this interval, in form of digital counts, completes the process of interrogation.

The flow chart for interrogation here involves the generation of clock signal i.e. analysis of transmit and receive pulses and digital counting of interval between **them** and its storage, as well.

The procedures, illustrated in the flow chart (fig. 5.3) are self -explanatory.

5.3.3 FLOW CHART FOR DATA DISPLAY

Each search point has its different position signals (x and y-coordinates) and corresponding z-signal. All these signals after being converted into digital forms are stored as x,y, and z-coordinates. These signals are given out in the same sequence, as stored.

The flow chart describing the various procedures is shown in Fig. 5.4. These procedures are explained as below:

At first, all the three ports of 8255 (P_2) are configured as output port. HL pair of registers are initialised as data pointer, being loaded with the same contents i.e. address o the memory location from where the data to be displayed, starts. A 16-bit counter, consisting of internal registers B and C is resetted to count the number of search points for which the data have been given out. The x,y and z signals are given out in succession. When the data for entire search points, have been outputted, the same process is repeated by loading the counter and data pointer with their original values.

5.4 CIRCUIT DETAILS AND DESIGN CONSIDERATIONS

5.4.1 THE TRANSMITTER

The circuit (fig. 5.5) here used to shock excite the ultrasonic transducer generates a voltage step across the transducer by discharging a capacitor voltage (charged to 50 v) into the transducer.

The active element is medium power and medium frequency transistor SL 100, which acts as a short circuit when the base is made positive by the application of a spike pulse to it. The spike pulse is produced by an incoming differentiator circuit. The differentiator circuit generates two spike pulses; one, positive going and the other, negative going. The negative going pulse is clipped off through a diode, configured in forward biased mode.

In order to keep the duration of the transmitter pulse as short as possible, the capacitor value (C) is kept, fairly low. But this requires the supply potential to be large. Hence, a compromise is made between supply potential and the capacitance value to get a sufficient amplitude of transmitter pulse with appropriate duration. Such a compromise, puts a limitation to the present system. This limitation here, mainly governs resolution of the system and to some extent its flaw detectability.

5.4.2 TRANSDUCER POSITIONING ARRANGEMENT

The entire region of interest, under test, is considered to be in the same plane. The piece is also assumed to be in a rectangular shape. This facilitates to divide the desired region to be scanned in square blocks of very small dimensions. This small square block is taken as one search points to fix up the transducer and search for a flaw. This square block here, serves as a search point in the cartesian coordinate plane. The transducer moves one unit in one step as decided by the software program. The movement of transducer in the two different axes is controlled by the software program running on the CPU. One corner of the rectangular plane is treated as the origin and serves as the reference for other points in the plane.

The transducer, performing both transmit and receive phenomena, is attached to the positioning assembly (Fig.5.6) The assembly comprises of two stepper motors and two rack and penion sets (one for each stepper motor,) with slides for transducer movement.

The mechanism is so adjusted that it provides motions in two perpendicular directions. The transducer is fixed at the search point through a proper coupling media (as earlier indicated, its movement is controlled by a software program).

As stepper motor moves always in steps. Its forward or backward motion (over a complete cycle) is only possible, when its different windings are excited in a proper sequence [25]. In this particular mechanism, the excitation of windings in requiste sequence is executed through the generation of code sequences [24], by the CPU. The proper amplitude of exciting signal is provided by a power module. This power module is an intermediate device between CPU and the stepper motor. The code sequences, generated by the CPU, are fed to the power module which subsequently produces the amplified signals in the same sequence and thus, excites the stepper motor windings.

The position signal is the total count of the earlier executed steps in both x and y directions. The counting is done in two different internal registers of CPU. One of them represents the x-axis and the other, the y-axis step movements. At each step these position signals (x-axis and y-axis counts) are stored. For this position signal, there exists a corresponding searched signal also, which is stored subsequent to these signals, each time.

5.4.3 ANALOG PROCESSING UNIT

The analog processing unit consists of amplifiers and subsequent demodulation and suppression circuits. Each of these is discussed separately in following sections.

5.4.3.1 The Amplifier

One of the basic criterion for amplifier design, in pulse echo system, is the frequency response of the amplifier. The first stage of the amplifier is a high frequency amplifier commonly, known as radio frequency amplifier in such systems. This should be of a very large bandwidth i.e. covering all occuring ultrasonic frequencies e.g. from 1 to 10 MHz. Signal-to-noise ratio (SNR) limits the selection of a very wide bandwidth because the noise signal varies proprotionally to the square root of the band width [15]. In addition, the harmonics of the frequency of the probe, often predominate in the frequency band of echoes, as compared with the harmonics of the harmonics of the transmitted sound wave. This poses the problem on the screen, producing undesirable background noise with which the flaw echoes to be detected no longer appear in clear contrast.

The operational amplifier LF 356 used in the present system provides an appropriate compromise among the above three parameters. It has a frequency band of 5 MHz and a noise of extremely low level, which has no significance as compared to the received signals from the transducer. The harmonics just indicated, in this case cause no problems because they are clipped off due to the limited bandwidth of the amplifier.

The paralysis problem (section 3.4.2.5) here is also avoided by using the two simple diodes connected, in opposition to each other, across the transducer in series combination with a resistor (Fig. 3.18).

The second stage of the amplifier is the video amplifier. As discussed (section 3.4.2.7), the video amplification requires almost the same characteristics as the radio frequency amplifier. Thus, LF 356 also serves here, as a video amplifier stage. However, no paralysis problem is encountered at this stage.

5.4.3.2 Demodulation and Suppression Circuit

The output from the rf amplifier is the faithful amplification complete with both positive and negative going excursions (as short clamped wave trains at 2.5 MHz). Since the identification of the received pulse is viewed only with its magnitude, the nagative going half cycle is cut off using a simple diode. The proper wave shape is obtained by suppressing the signals through a RC network at each amplifier stage.

5.4.4 PULSE CONVERTER

The transmitted and received echo pulses, obtained from the analog processing unit are in spike form. Their value ranges from 5 to 10 V. For the digital processing, the above pulses are required to be in the form of rectangular pulses and their value must lie between 3.6V to 5.0 V (TTL level) so that the devices following it may sense it encountering no damage or unusual behaviour. The circuit, shown in Fig. 5.7, fulfills the above requirement. It consists of an operational amplifier 741, a zener diode with breakdown voltage of 5.0 V and a transistor for switching.

5.4.5 DIGITAL PROCESSING UNIT

The first function of digital processing unit (Fig. 5.8) is to separate out the transmitted and received pulses from each other. The function is achieved through logic inverters, AND and Ex-OR gates. In addition to the final output at the final stage of the analog devices, (section5.4.3and 5.4.4) one more signal is generated having the same phase and frequency as of the pulse repetitiom. The pulse length of this particular signal is slightly greater than that of the transmitted pulse of the signal comprising both transmitted and received pulses. By ANDing these two signals (output signal from the pulse converter and the just generated signal) it is thus, possible to generate a signal of frequency equal to the pulse repetition frequency but free from the received echo pulses. This generated pulse is Ex-Ored with the signal having both transmitted and received pulses and consequently, provides a signal which comprises only received echo pulses.

The next step in the digital processing is the generation of a pulse of length equal to the time interval between the transmission and reception instants (for the first received echo only). This is achieved by using a 555 timer in bistable mode [13]. In the case, the transmitted pulse acts as trigger pulse while the first received pulse does the resetting. The CPU is fed with the output of the 555. It measures the pulse length in digital counts and finally stores it as z-axis coordinate.

5.4.6 THE IMAGE PROCESSING AND DISPLAY UNIT

As indicated earlier, all the three coordinates (x,y and z) are stored in digital form. It is thus, desired to convert them into analog signals for displaying them on CRO. The digital-to-analog converter (DAC), DAC 0800 is used for the purpose. The x,y and z signals are given out in succession by the CPU and fed to the CRO through the DACs. The spot movement is determined by the x and y coordinates and its intensity by the z coordinate. When all the information is repeated in quick succession, a stationary image is seen on CRO screen, which depicts the cross-sectional view of the specimen scanned.

The CRO used is non-storage type made by Systronics. It has the frequency bandwidth of 5 MHz, ranging from dc to 5 MHz. With the scanning done in descrete fashion the CRO presents only a matrix of spots, one for the each search point. However, the spot intensity is governed by the interval count; a low count gives low intensity and vice versa.

5.5 HIGHLIGHTS OF THE NEW SYSTEM

In chapter IV, the B-scan concept and its available instrumentation schemes were discussed. Basic principles of C-scan were also discussed in Chapter III. While B-scan presents the cross-sectional image of a section, the C-scan produces the same but towards the front. The developed system here, also provides the cross sectional view but towards the front face as a C-scan does. The difference lies in the fact that C-scan is able to generate an image while receiving the intensity change in the transmitted pulse from the other side (opposite to transmitting side), the present system does it by receiving the return echo and judging it only by its transit time. In this way, it resembles with B-scanning.

Another point worth noting is that though the present system converts the transit time into a signal to brightness modulate (z-modulate) the CRO, the conventional B-scan and

C-scan images have z-modulation signal through the conversion of amplitude of echo pulses into brightness signal. This specific feature enables the present syster to present more informations than the other two scan images. It can distinguish between the flaws of near and farther locations, in case, the near flaw does not masks the further one. Using this feature it is best suited to complement and even present a comparable result with the x-ray radiography.

The electronic circuit is almost similar to the conventional B-scan and C-scan imaging systems. The elements of analog processing and digital processing units are designed on the basis of scanning mechanism used ; for mechanical scanning it should have some specific features while for electronic scanning the requirements are different. Chapter IV clearly describes those requirements.

The present system based on pulse - echo technique uses the linear scanning mechanism(section 4.3.2) . The linear motion is provided by the stepper motor movement controlled by microprocessor. The system is of contact scanning type since the transducer, here, is in direct contact with the test piece. The transducer movement is automatic i.e. controlled by the system itself. The system is programmed and configured in such a way that without proper coupling, the movement of transducer is not possible and hence no further scanning can be carried out.

The system is a non-real time imaging type since during scanning no display is observed. This is seen only after the completion of scanning. This limitation here, is only due to the CRO because it is a non-storage type. Thus, it can be converted to a real time imaging system using a storage type of CRO. A slight modification in the software is needed to accomodate the storage of information and subsequent display. In an ideal sense, we can not get the real time imaging system because there is always some time delay between transmitted signal and the received signal and associated processing units also, cause some delay. But, according to the definition (section 4.3.3) it is possible to get a real time image from this system, also.

The transducer used here, has a diameter of 15 mm and its natural frequency as 2.5 MHz at which it produces the ultrasonic waves. The generation and reception of the waves is entertained by same transducer. The transducer has a low damping.

The most important feature of it is that it utilizes the digital computer technology for most of the activities. This facilitates generation and storage of the position signal and processing and storage of transit time information.

5.6 RESULTS AND COMMENTS

The system has been tested on a self-made test piece having an imaginary flaw in its centre part. The presence of flaw and its approximate shape towards front is viewed as the brighter portions in the image on CRO screen. For the test piece here, the image achieved is shown in photograph P_{10}. The image quality is not a very good one. The main limitation lies in two facts: the first one, is the diameter of the transducer (here 15 mm) and the other, is the memory storage area (only 1296 locations available). The memory storage can be increased easily but the transducer diameter remains a limitation. Although, the image seen at CRO is made of deserete points, it gives a good idea of the flaw shape.

The scanning process is somewhat slow due to involvement of a long delay between steps of the movement of the transducer. This slow scanning is necessitated by the large inertia of the stepper motor. However, at present, the fastest scanning speed, possible with the given stepper motors, has been implemented.

The square pulse generated (pulse repetition frequency), is shown in photograph P_1. In the photograph P_2 and P_3, the differentiated signal (negative going edge elipped off), fed to the transmitter can be seen. The pulse repetition frequency is 440Hz and the pulse width is 2250µs. Amplitude variation of transmitted output fed to the transducer can also be observed in the same, P_2 and P_3 photographs. When the probe is not connected, the transmitted output is 30 V. It reduces to 10 V

When the probe is connected across the transmitter . The impedance mismatch at transducer input and output stages (receiving stage) plays a great role in such voltage drops. The voltage, however, here is at its best possible matching condition.

The receiver output (after the first stage of amplification) is shown in photograph P_4. The final output is also seen in the same photograph. This shows the presence of received echoes. The various input and output signals at different stages of digital processing unit can be viewed in photographs P_5, P_6, P_7 and P_8. A special signal has been generated for ANDing the output rectangular pulse (produced by the pulse converter). This particular signal, now becomes the limiting factor for the system resolution replacing the other inherent limiting factors, such as, transmitter spike pulse duration, damping of the probe and bandwidth of the amplifiers used as receivers. Interval pulse for different flaw locations, is seen in the photograph P_7 and P_8. A comparative view of these presents the obvious distinction between them lying in its transit time (Here, pulse duration).

The position signals for x and y -axis movements (coordinates) are in the shape of ramps. One ramp of the y-signal consists of 32 ramps of the x-signal. The complete experimental set up can be seen in photograph P_9.

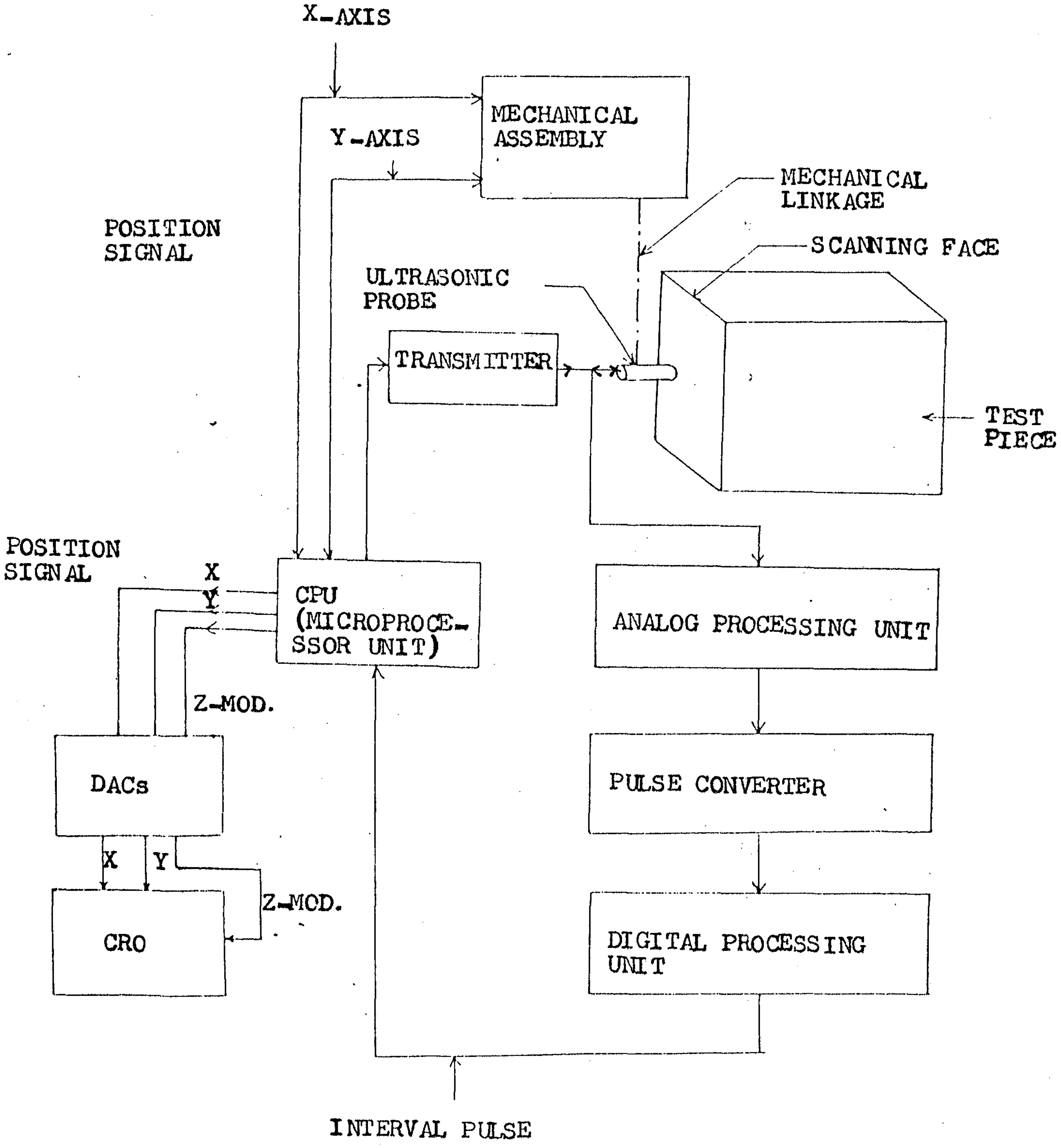
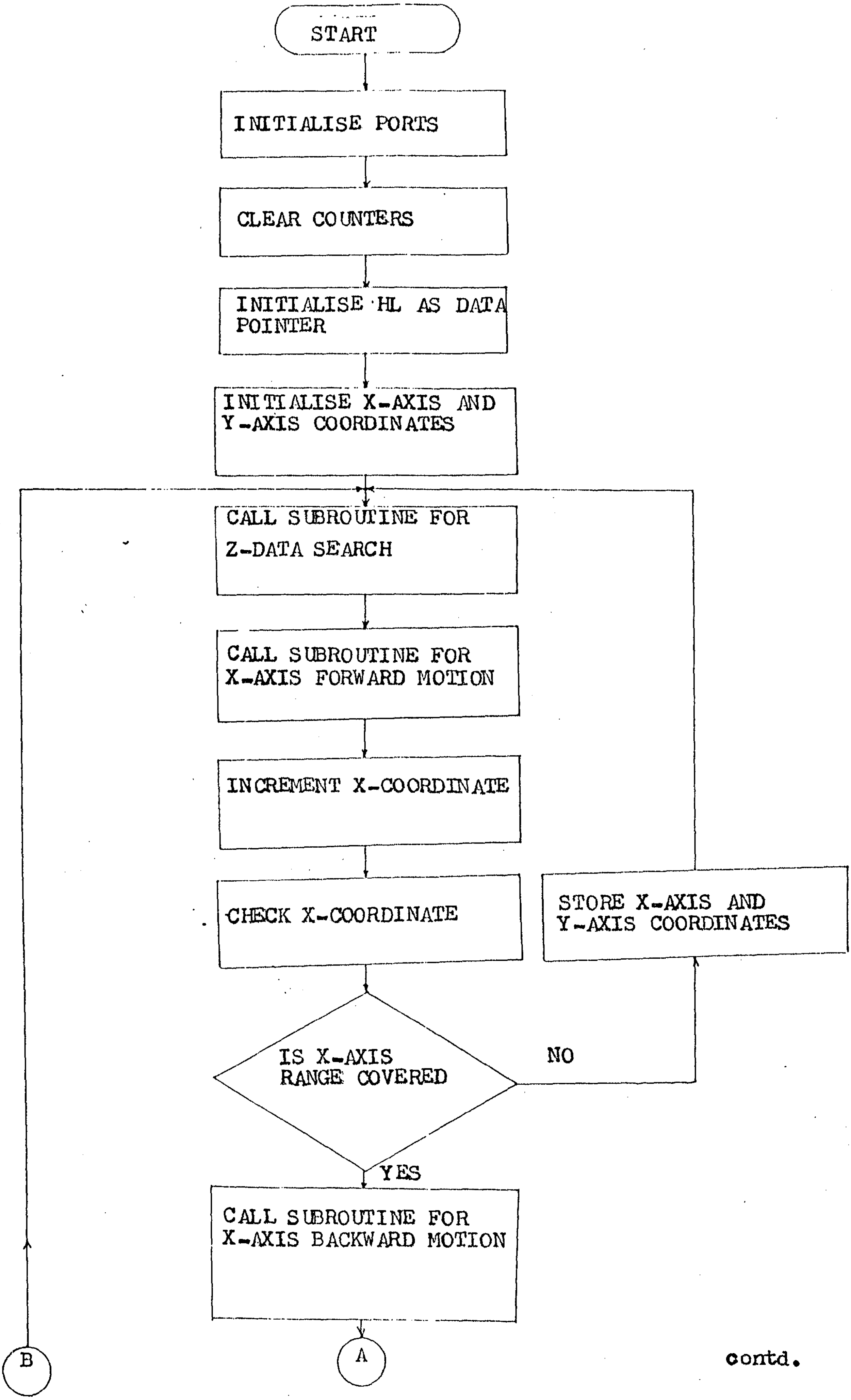


FIG. 5.1 COMPLETE SCHEME OF THE DEVELOPED ULTRASONIC IMAGING SYSTEM.


START
INITIALISE PORTS
CLEAR COUNTERS
INITIALISE HL AS DATA POINTER
INITIALISE X-AXIS AND Y-AXIS COORDINATES
CALL SUBROUTINE FOR Z-DATA SEARCH
CALL SUBROUTINE FOR X-AXIS FORWARD MOTION
INCREMENT X-COORDINATE
CHECK X-COORDINATE
IS X-AXIS RANGE COVERED
NO
STORE X-AXIS AND Y-AXIS COORDINATES
YES
CALL SUBROUTINE FOR X-AXIS BACKWARD MOTION
A
B

contd.

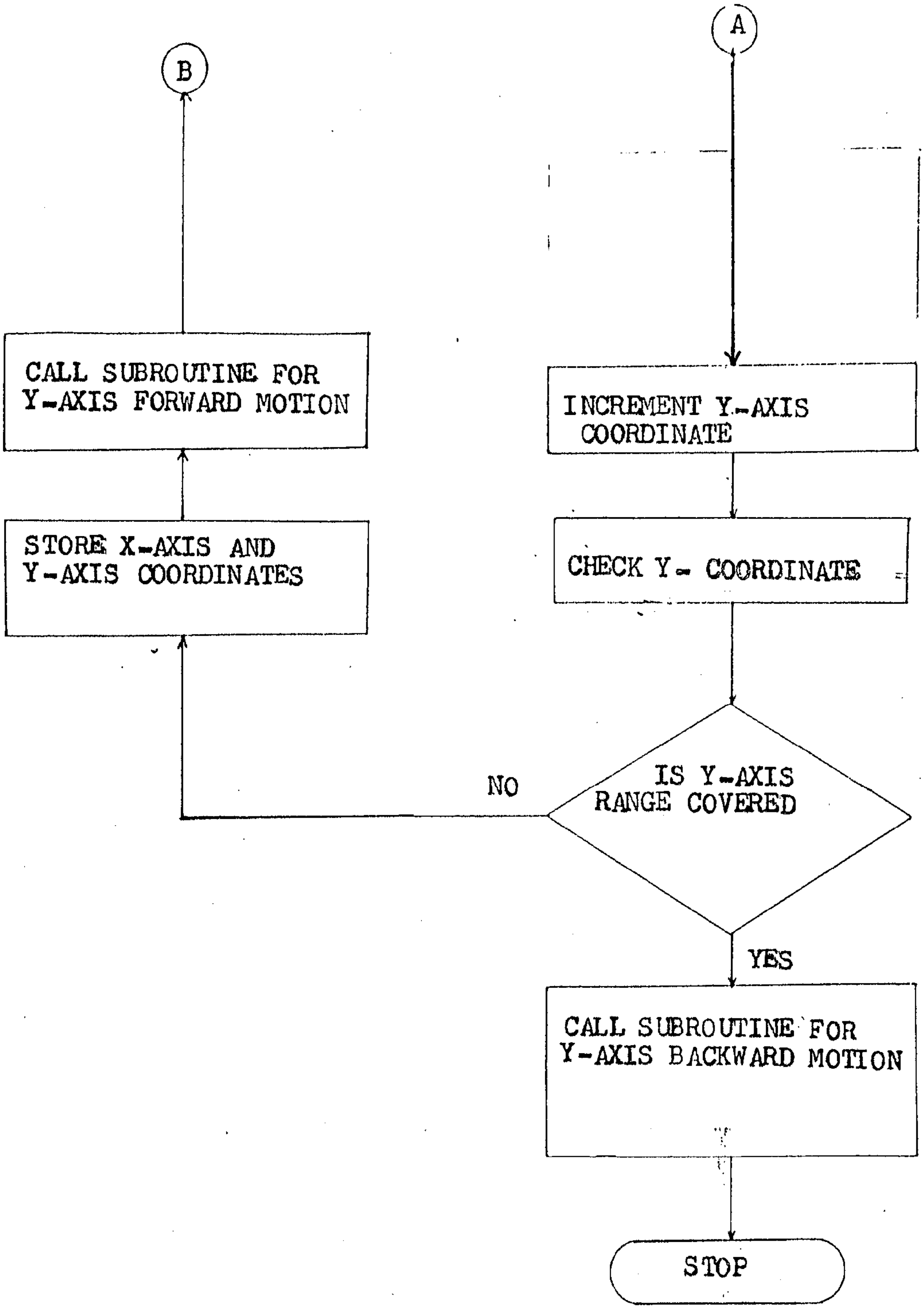


FIG. 5.2 FLOW CHART FOR SHOWING COMPLETE OPERATION OF THE IMAGING SYSTEM.

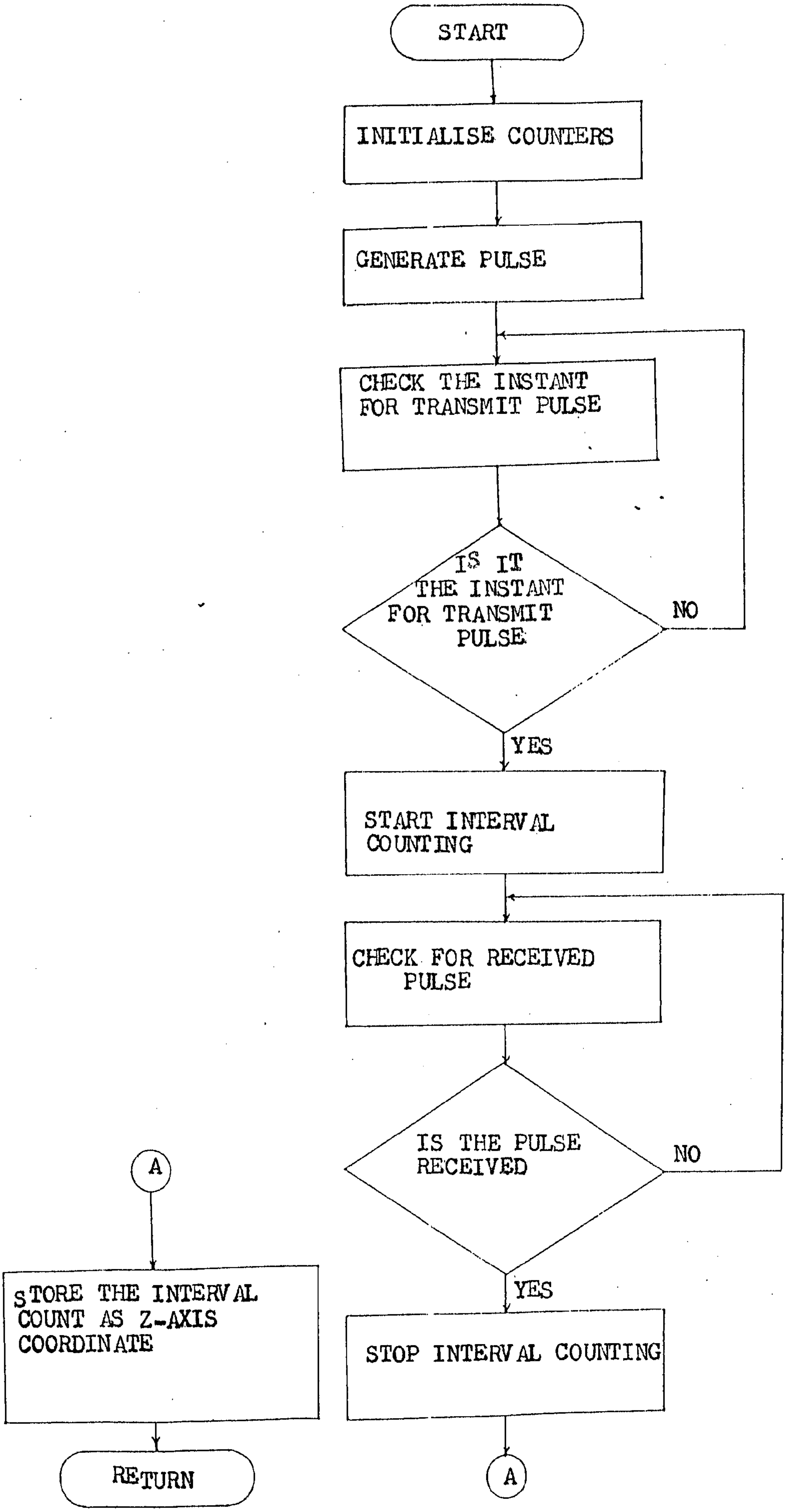


FIG.5.3 FLOW CHART FOR Z-DATA SEARCH

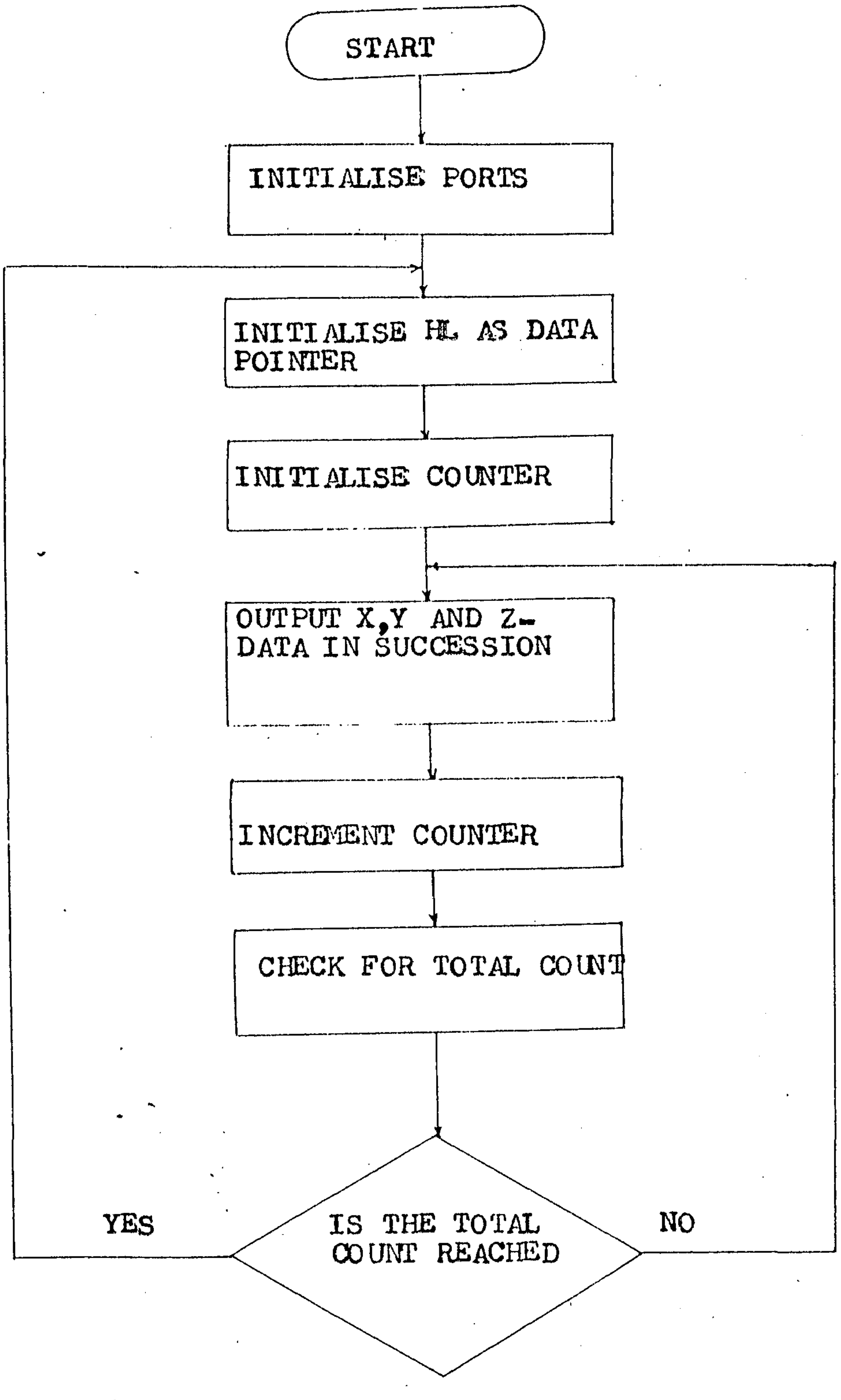


FIG 5.4 FLOW CHART FOR DATA DISPLAY

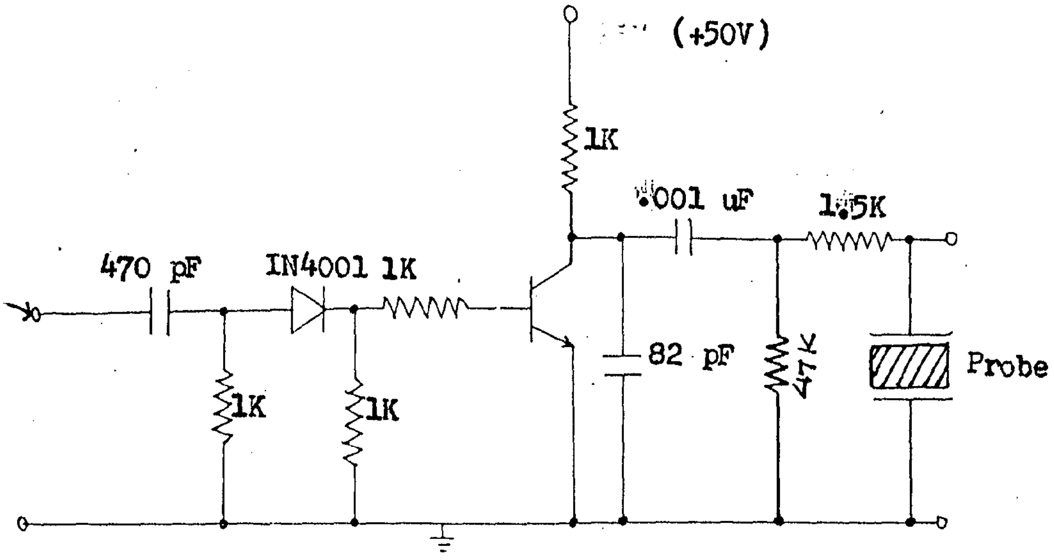


FIG. 5.5 Transmitter Circuit.

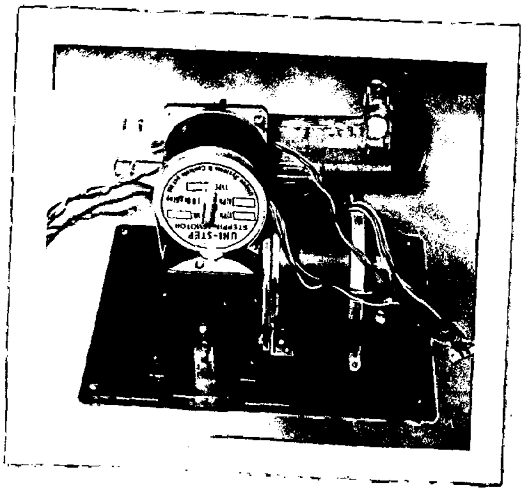


Fig.5.6 Scanning Mechanism.

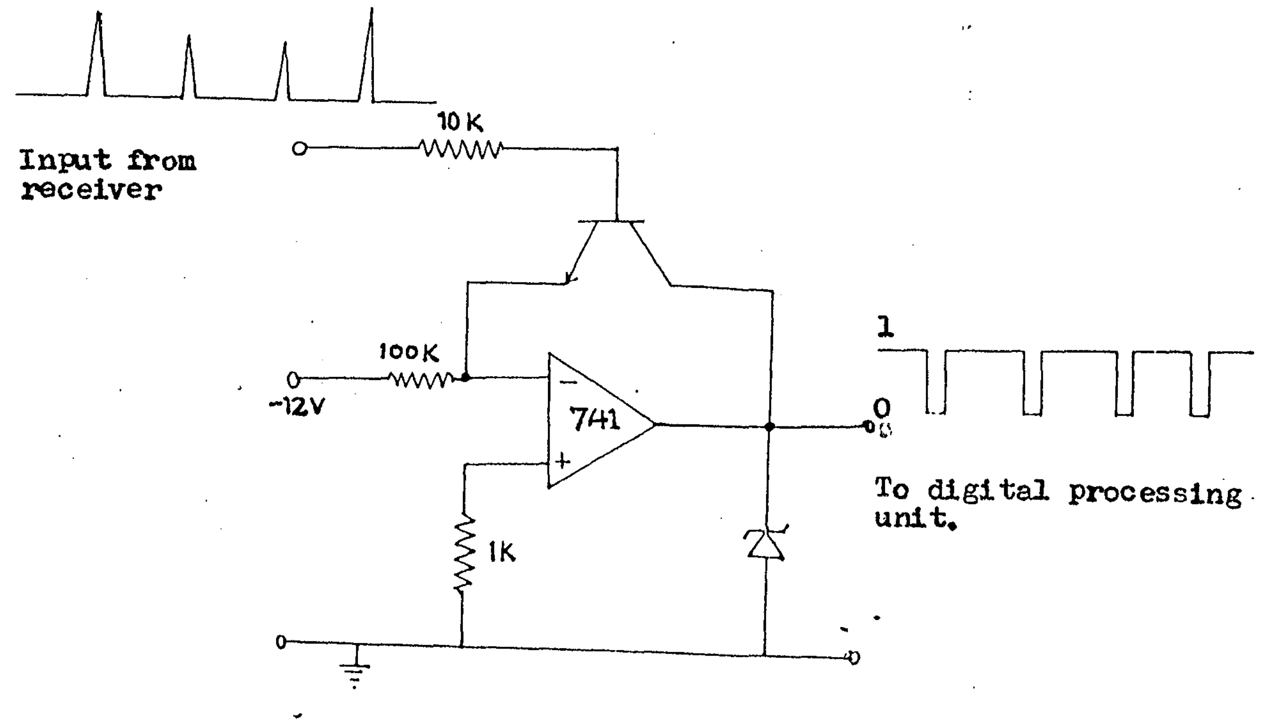


Fig. 5.7 Pulse Converter Circuit.

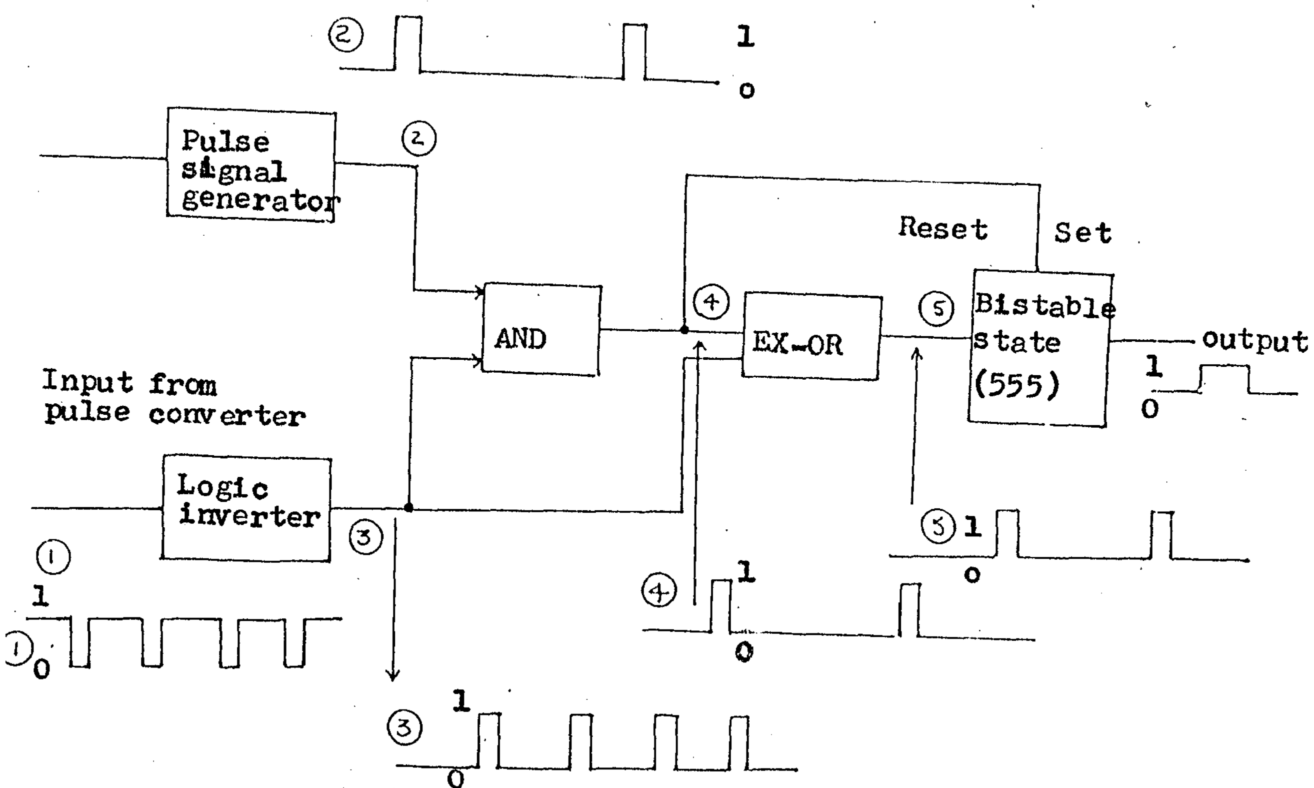
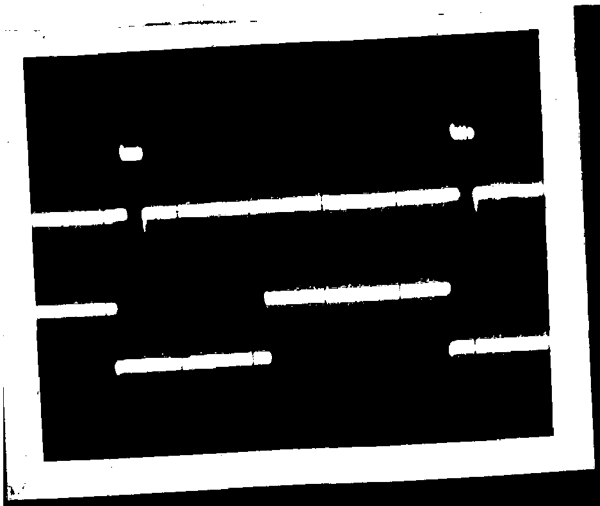
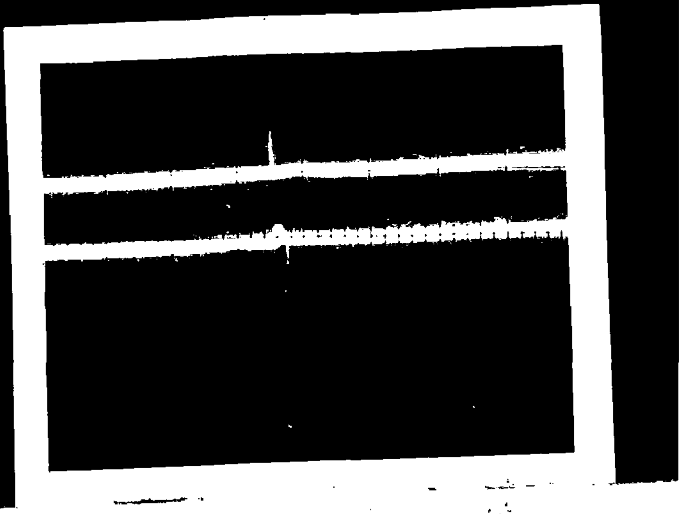


Fig. 5.8 Digital Processing Unit

(a) Transmitted pulse in rectangular form.

(b) Clock output from CPU



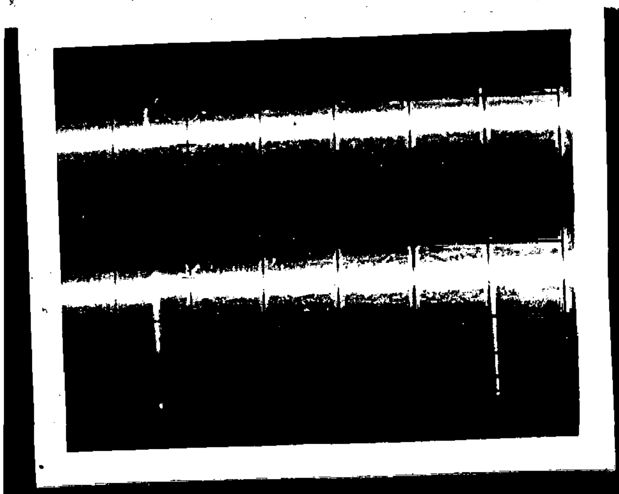


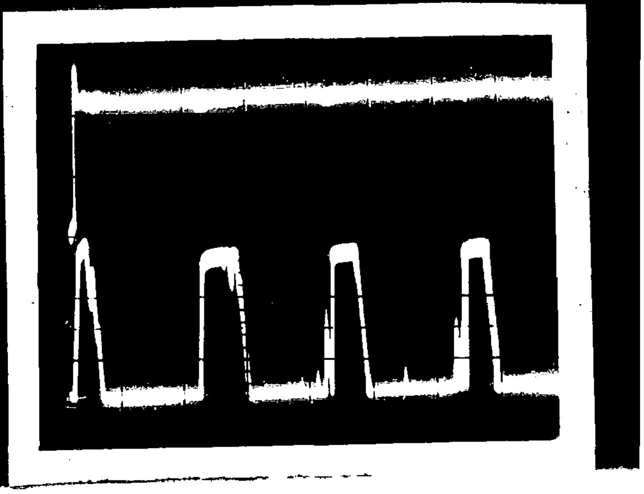
P$_2$ (a) Differentiated input fed to transmitter.

(b) Transmitter output (probe unconnected)

3 (a) Differentiated input to transmitter.

(b) Transmitter output (probe connected)



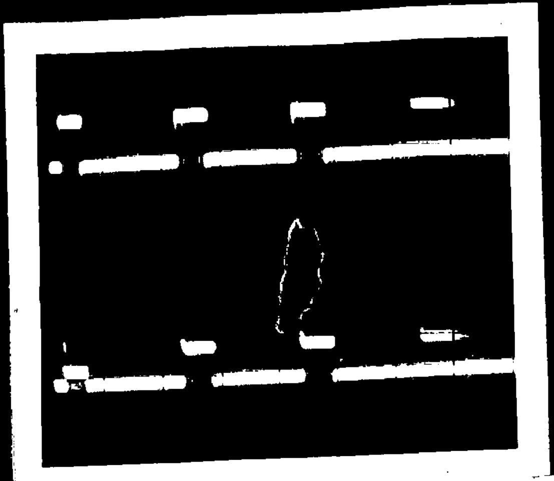


P$_4$ (a) Output at rf amplifier stage (received echoes but in demodulated form slightly observable.

(b) Output of the receiver (final output: received echoes clearly observable)

P_5 (a) Logic inverter stage output (signal consisting of transmitted and received both pulses).

(b) ANDed output (only transmitted pulse).

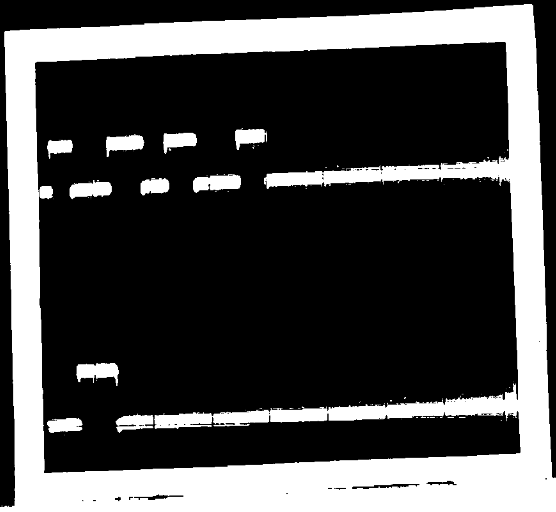


P_6 (a) Logic inverter stage output (Signal consisting of transmitted and received both pulses).

(b) EX ORed output (only received echo pulses).

P_7 (a) Signal consisting of transmitted and received echo pulses.

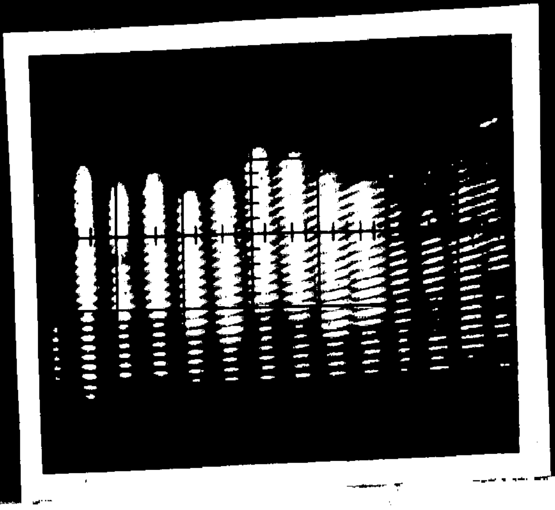
(b) Transit time pulse for first return echo (flaw at 70 cm).



P_8 (a) Signal consisting of transmitted and received echo pulses.

(b) Transit time for first return echo (flaw at 35 cm).

P_9 Complete Experimental set up.



P_{10} Image obtained for the flaw shape.

CHAPTER - 6

CONCLUSIONS AND DISCUSSIONS

The ultrasonic imaging system, developed by the author, is an effort to explore the diagnostic area of ultrasonics in industrial non-destructive testing applications. The non-destructive testing is a most challenging field for research and development requiring states of art in electrical engineering technology. Thus, it requires fundamental advancements to provide a better means for characterising material defects to give metallurgists, the detailed information necessary to access the failure potential of known anamalies.

The developed ultrasonic imaging system based on pulse-echo method gives better results when compared with the B-scan and C-scan imaging systems.

The transmitter voltage, here, required for deep penetration is much less than any other earlier pulse echo systems. Thus, it completely removes the hazardous effects caused by the high voltage. The complexities encountered in generation of position signal through analog devices have also been eliminated by the application of digital computer technology (Microprocessor-8085 has been used as the central processing unit). It further removes the requirement of external clock generating device since the clock, here, is generated by the CPU itself. The CPU also controls the movement of scanning mechanism and thus the position of transducer.one important factor associated with the system is that it never produces undesirable information about the flaw because the scanning of the further points is carried out only when the transducer is properly coupled to the present search point and collects the information regarding the presence or absence of the flaw.

The reception and storage of transducer position signals is quite easy. The interrogation at particular search point is free of any complexity. When the entire region of interest in test piece is scanned,stored data is displayed on CRO, which shows the internal structure of the test piece(only for the region scanned) towards its front side. In case the near flaw masks the further one, no information regarding it can be observed. This is the limitation of the sound wave propagation and is an inherent drawback of all the ultrasonic imaging systems. The shape of the flaw at different locations can be realized by viewing the brighter and darker spots in the image on CRO. The image, obtained by the system, is in form of a matrix of spots. This can be converted to a continuous picture with the use of focussed transducers (having its focussing area in fractions of mm) and a large memory area (for its image storage).

The another scheme developed is A-scan providing flaw location in numerical readout. The digital indication in this system improves readability. The conversion of transit time into digital counts facilitates further extension of the scheme for process control purposes. The accuracy of the system depends upon its calibration to particular material velocity and the design of clock signal utilised for counting. For the present system, the calibration is meant for the brass material only. So, all the informations received are valid only for brass material. The system is enabled to detect the flaws in other materials giving its exact location by changing the calibration. The incorporated counting method eliminates the error arising out of additional time constants encountered in the integration method. The system thus has a very high speed of response. The resolution of the system can be improved by using a transducer of low damping. The pulse length of the transmitter output, which is the another factor for deciding the resolution limit, can also be reduced by employing a higher supply voltage and a lower value of capacitance in the transmitter circuit to achieve a better resolution.

Test conditions limiting the application of this ultrasonic imaging system are

1. Unfavourable sample geometry e.g. size, contour, complexity and flaw orientation.
2. Heterogeneity in interval structure e.g. grain size structure porosity, inclusion content, or fine dispersed particles.
3. Improper coupling.

SCOPE FOR FURTHER WORK

The most important scope for extension in the present system is replacement of the flat transducer by the focussing transducer of a very low focussing area so as to increase the resolution of the system. The availability of a large memory area for data storage can provide a fine picture instead of a dot matrix.

Replacing the entire search unit (including its positioning arrangement) by a linear stepped array (or linear phased array) the system can produce results comparable to x-ray radiography. In this way, it can serve a better purpose since it encounters no hazardous effects caused by exposure to x-rays. The present imaging system,which now is a non-real time type,can be converted to a real time imaging system by employing a storage type of CRO in place of a non-storage type presently used. In such a case, it will be able to produce a moving picture of the test piece scanned in the pattern of transducer movement.

REFERENCES

1. Fredrick J.R., 'Ultrasonic Engineering', John Wiley and Sons, Inc. New York, 1965.
2. Mason W.P., 'Sonics and ultrasonics: Early History and Applications', IEEE Trans. Sonics and Ultrasonics, Vol. SU-23, No.4, pp.224-231, July 1976.
3. '1986' Year Book of Science and Future', Encyclopedia Britannica, Inc. Chicago, 1986.
4. Erikson, K.R., et.al., 'Ultrasound in Medicine- A Review', IEEE Trans. Sonics and Ultrasonics, Vol. SU-21, No.3, pp.144-164, July 1974.
5. Krantbramer J. and Krantkramer H., 'Ultrasonic Testing of Materials', Springer Berlag Berlin Hiedelberg, New York, 1977.
6. Schueller C.F., Lee et.al., 'Fundamentals of Digital Ultrasonic Imaging', IEEE Trans. Sonics and Ultrasonics, Vol. SU-31, No.4, pp. 195-216, July 1984.
7. Smith A.L., 'Ultrasonic Testing Fundamentals', Materials Evaluation, Vol. 36, No.5, pp. 22-31, April 1978.
8. Yoneyama H., et. al, 'Ultrasonic Testing of Austenitic stainless Steel Weldments by Means of transmitter-Receiver Type Longitudinal Wave Angle-Beam Probe', Materials Evaluation, Vol. 40, No.5, pp.554-558, April 1982.

9. Rasmursen J.G., 'Ultrasonic Surface Waves - Prediction of Fatigue Failure', Materials Evaluation, Vol. 20, No.2, pp. 103-104, February, 1962.

10. Parker Sybil P. (Editor in Chief), 'Mc Graw Hill, Concise Encyclopadia of Science and Technology', Mc Graw Hill Company, New York, 1984.

11. Wells P.N.T., 'Biomedical Ultrasonics' Academic Press, London, 1977.

12. Trikande M.W. 'Design and Development of Ultrasonic Instrumentation System', M.E.Dissertation, University of Roorkee, Roorkee, India, 1986.

13. Berlin H.M., 'The 555 Tuner Applications Source Book with Experiments', Howard W.Sams and Co. Inc. INDIANA, USA, 1982.

14. Martin R., 'Variable Pulse Width Ultrasonic Transducer Driver', NDT International, Vol. 17, No.4, pp. 209-213, August 1984.

15. Mukhopadhyaya P., 'Special Lectures on Noise in Electrical/ Electronic Circuits', A Measurement and Instrumentation Activity, Department of Electrical Engg., University of Roorkee, Roorkee, INDIA, November 1985.

16. Lunt R.M., 'Handbook for Ultrasonic B-scanning in medicine', Vol.1, Cambridge University Press, Cambridge, London 1978.

17. Kessler L.M. and Yuhas D.E., 'Acoustic Microscopy- 1979, Proc. IEEE Vol. 67, No.4, pp. 526-536, April 1979.

18. James F.M. and Jon C.T., 'Medical Ultrasonic Imaging: An Overview of Principles and Instrumentation', Proc. IEEE. Vol. 67, No.4, pp. 620-639, April 79.

19. Schafer E.M and Lewin A.P., 'The Influence of front-End Hardware on Digital Ultrasonic Imaging', IEEE Trans. Sonics and Ultrasonics Vol. SU-31, No.4, pp.295-304, July 1984.

20. Hunt J.W., Arditi M. and Foster E.S., 'Ultrasonic Transducers for pulse-Echo Medical Imaging,'IEEE Trans. Biomed Engg. Vol. BME-30, pp. 453-487, 1983.

21. Maginers M.G., Methods and Terminology for Diagnostic Ultrasound Imaging Systems', Proc. IEEE, Vol.67, No.4, pp. 641-653, 1979.

22. Ophir J.and Maklad N.F.,'Digital Scan Converters in Diagnostic Ultrasound Imaging', Proc. IEEE Vol.67 No.4, pp. 654-664, 1979.

23. Mathur A.P., 'Introduction to Microcomputers', Tata Mc Graw Hill Publishing Company Limited, New Delhi,1983.

24. Vinytics 'User's Manual for Interface Modules'.

25. Kenjo T., 'Stepping Motors and Their Microprocessor Controls', Clarendon Press, Oxford,1984.