NONDESTRUCTIVE TESTING OF CONCRETE BY ULTRASOUND

by

Ali Sina KUMCUOĞLU

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This thesis, submitted by Ali Sina Kumcuoğlu to the Electrical Engineering Department of Boğaziçi University in partial fulfilment of the requirements for the degree of Master of Science, is approved.

Dr. Adnan Kahveci
(Thesis Advisor)

Doç. Dr. Okan Ersoy

Dr. Yani Iskarlatos

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ABSTRACT

In this thesis, nondestructive testing of materials using Ultrasonic techniques has been investigated. Especially the determination of the quality of concrete, how the sonic wave behaves in concrete, relation of acoustic velocity to Elasticity Modulus and to compressive strength, and other problems of testing procedure have been examined.

An instrument is built up for this purpose which is designed to measure the transit time of sound propagation in a medium between two Ultrasonic Transducers and to display it in microseconds. Thus, the velocity of sound in the medium can easily be derived. If the medium is concrete, then, from the velocity the quality of concrete and other parameters can be determined. The instrument in fact can easily be adapted for transit time measurements of other kinds of materials or media for testing purposes.

The instrument basically consists of transmitter and receiver circuits, counter, control unit and transducers. With the start pulse the circuit starts counting and at the same time the Ultrasonic wave is transmitted. With the stop pulse which is created after detection of the sonic wave, counting ceases and

the time elapsed occurs on the digital display. The instrument also makes it possible to locate the depths of the flaws inside e.g. cracks, and to determine thickness, if sound velocity in the sample is known.

INTRODUCTION

Generally, to determine the mechanical properties of a given material, the mechanical method is the most direct and ready to hand. To determine whether a shaft is cracked inside, it can be stressed by tension or bending until the crack manifests itself by an open break. This is a mechanical but unfortunately destructive test. In the same manner, the disadvantages of the standart method of testing the quality of concrete by crushing test cubes are well known and have led to a large number of attempts to test the strength of concrete by non-destructive means.

Ultrasound offer, for the same purpose, non-destructive methods which basically likewise use mechanical stresses produced by tensile, compressive, shearing, or flexural forces but which are of low intensity. By Ultrasonic non-destructive methods, several tests can be made in many kinds of material, such as flaw detection on metallic specimens, heavy forgings, worked parts of machines, railway material, plates, semi-finished products as rods, billets and wires, pipes and cylinders, castings, welded joints, steel, iron, copper and its alloys, aluminium; non-metallic specimens as every kind of concrete construction, porcelain, glass, plastics, rubber, natural rock, wood, leather, bacon and meat. (1).

Sound is propagated in the form of a mechanical vibration of the particles of the medium through which it travels. If the particle vibration occurs in the direction of sound propagation then this is called the longitudinal wave if particle motion is perpendicular to the direction of sound propagation then transverse waves are created. Transverse waves occur only in solids.

The human ear is sensitive to sonic frequencies in between 10 Hz to approx. 16 or 20 kHz. The frequencies above 20 kHz are inaudible to human ear, and are referred to as Ultrasound or Ultrasonics. Ultrasonic waves occur in nature and in daily life, e.g. in the case of steam whistles, a rotating grindstone or jet engine, Ultrasound is generated at frequencies of above 100 kHz or even up to10 MHz. (1)

The velocity of sound depend on the elasticity and density of the medium it travels through. Simply,

$$V = \sqrt{\frac{E}{\rho}}$$

E = Elasticity
ρ = Density

Elasticity is the measure of stiffness of the elastic connection between the particles of a material. The stiffer the material the higher the elasticity is. Typical sound velocities in various media are, (m/sec) (2)

Air: 331 - 340	Water: 1430	Seawater: 1531
Plastic: 2500	Steel: 5000	Marble: 3810
Wood(Oak): 4100	Concrete: 2000 - 4500	

In order to convert electrical signals to mechanical movement or mechanical movements to electrical signals, a suitable transducer is needed. Some very suitable materials exists for this job. These materials are called Piezoelectric. Some Piezoelectric (PE) materials are natural and some are synthetically made. Naturally occuring materials are quartz, rachellé salt, and tourmoline. Synthetically produced PE materials include, Barium Titanate, ($BaTiO_3$), Lead Zirconate,($PbNbTiO_3$), Lead Niobate. (3) Of the natural ones Quartz is the most often used. Synthetic PE materials vibrate in the direction it was poled. Its PE property exists only between the original poling electrodes it was poled with. PE materials will loose their PE property with mechanical or electrical use. In quartz this loss is the minimum, in synthetics this is very apparent. Thus, PE materials should never be subjected to excessive mechanical or electrical input.

Another way of creating Ultrasound is Magnetostrictive Sound Generation. Magnetostriction can be defined as the change in dimensions of a ferromagnetic material when subjected to an alternating magnetic field. An applied a.c. field will cause physical contraction and expansion in synchronism with the applied field. Suitable materials are Nickel-Iron, pure Iron and ferrites.

Acoustic velocity is independent of frequency, but the penetration of sound into different kinds of material depend on its frequency to a great extent,,e.g. High frequency Ultrasound will not travel in air.

I. THEORY OF NON-DESTRUCTIVE TESTING

1. METHODS OF MATERIAL TESTING BY ULTRASOUNDS

The most popular of the several methods used for non-destructive testing of materials by Ultrasonic means re (1),(4),(5) :

1.1. Resonance Method.

1.2. Intensity Method.

1.3. Pulse-echo Method.

1.4. Pure Transit Time Method.

1.1. Resonance Method:

In this method a movement at its natural frequency is applied to the specimen. The frequency of the exciting wave must therefore be changed continously until resonance occurs. The oscillation amplitude is highly increased by the effect of resonance. By the density and the resonance frequency the dimensions and the elastic properties of the material, its Elasticity Modulus, Poisson Coefficient can be stated. This method needs to much of expense and is used under certain circumstances in Lab. experiments.

1.2. Intensity Method:

In this method, the intensity of the Ultrasound is measured after it has passed through the test piece. At the flawed point the propagation of the Ultrasonic wave is impeded by the discontinuity in the material .

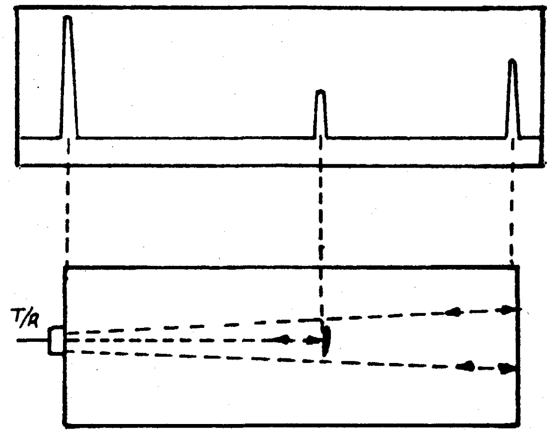


Figure.1. Small flaw in sound beam in Pulse-echo method.

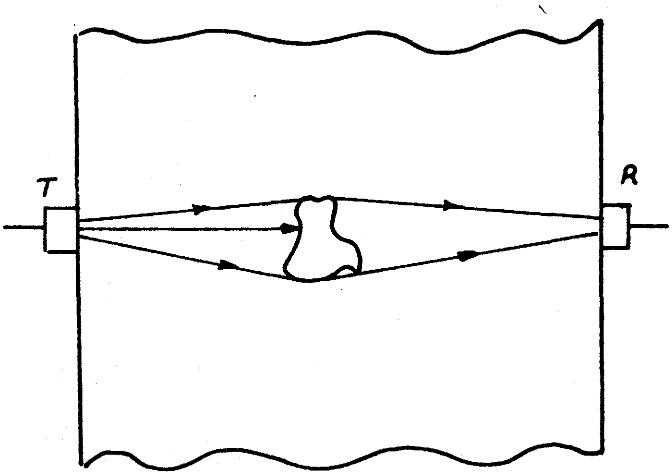


Figure.2. Pure Transit Time Method. Extension of travel time in the existence of an obstacle.

parts or sides of the specimen , is needed. The frequency should be much lower then in echo method so that a small enough damping can be created and with this the sonic pulse can penetrate through the material under test. This is so because at low frequencies Ultrasonic waves can refract easier at small obstacles and holes than at shorter waves. But on the other hand the beam sharpness becomes so bad that practically the source can be assumed approximately spherical. If the sound velocity in the material is readily known by measurements at the not dfected parts, then the existence of a flaw can be determined by the extension of travel time, i.e. decrease in velocity in the material. Because the sonic wave goes around the obstacle or hole the travel path gets longer. (fig. 2.) Then the elastic properties of the material are determined by the acoustic velocity through it. This method is suitable for testing of materials with normed sizes such as test cubes and also various construction elements such as, every kind of concrete construction, rock, road surfaces, fiberglass and other artificial materials, glewed pieces and constructions of wood.

The instrument that is built works on this method.

2. BASIC PRINCIPLES OF ULTRASONIC WAVES

2.1. Forms of waves:

If the density of the solid is 'g' and the velocity of the wave for a long rod shaped solid 'V', where the elasticity modulus is 'E'

$$V = \sqrt{\frac{E}{g}}$$

e.g. Let the density and the elasticity modulus of a concrete composed of large grains of sand be respectively,

$$g = 2500 \quad kg/m^3$$

$$E = 4.10^{10} \quad N/m^2$$

$$V = \sqrt{\frac{4.10^{10} \quad kg.m.m^3}{0,25.10^4 \quad s^2.m^2.kg}}$$

$$V = 4.10^3 \ m/s = 4 \ km/s$$

The relation between V and E for a specimen that its length is greater than the wavelength, is not so simple. Poisson has shown that (1), in an infinitly wide physical medium two different kinds of waves may exist. One is the Longitudunal Wave which its velocity is,

$$V_L = \sqrt{\frac{E}{g} \cdot \frac{(1 - \mu)}{(1 + \mu)(1 - 2\mu)}}$$

The other one is the transversal wave which has less velocity:

$$V_T = \sqrt{\frac{E}{g} \cdot \frac{1}{2(1 + \mu)}}$$

μ is the Poisson Coefficient and, $\mu = 0,2$ for the above mentioned concrete.

For $\mu = 0,2$,

$$V_L = 1{,}05\sqrt{\frac{E}{g}} \quad \text{Longitudinal Wave.}$$

$$V_T = 0.65\sqrt{\frac{E}{g}} \quad \text{Transversal Wave.}$$

This shows that the Longitudinal Wave is 5% faster, whereas the Transversal wave is 35% slower than the compound wave. For this reason the instrument only measures the Longitudinal wave. (fig.3.)

2.2. Group Velocity:

Since the Ultrasonic instrument always deals with the front face of a sonic pulse, then the instrument actually measures the group velocity of the material under test. This velocity is the velocity of the envelope of the pulse train. However, do not show any dispersion at usable region. This means that since the velocity of the sonic wave is independent of frequency, the travel time of the group is identical to that of the sonic wave. For the instrument this definition means that the pulse velocity is equal to the velocity of the Longitudinal waves. That is roughly the "Ultrasonic Velocity". This definition makes it possible that for V_L the formula above is still valid for any kind of normed size materialor a costruction element. The path and the kind of measurement is important

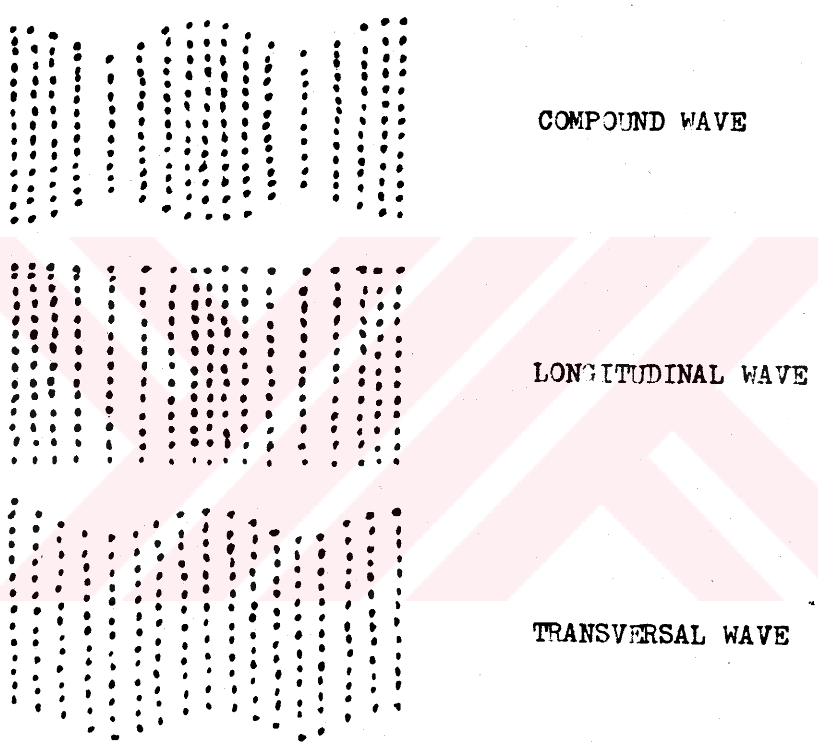


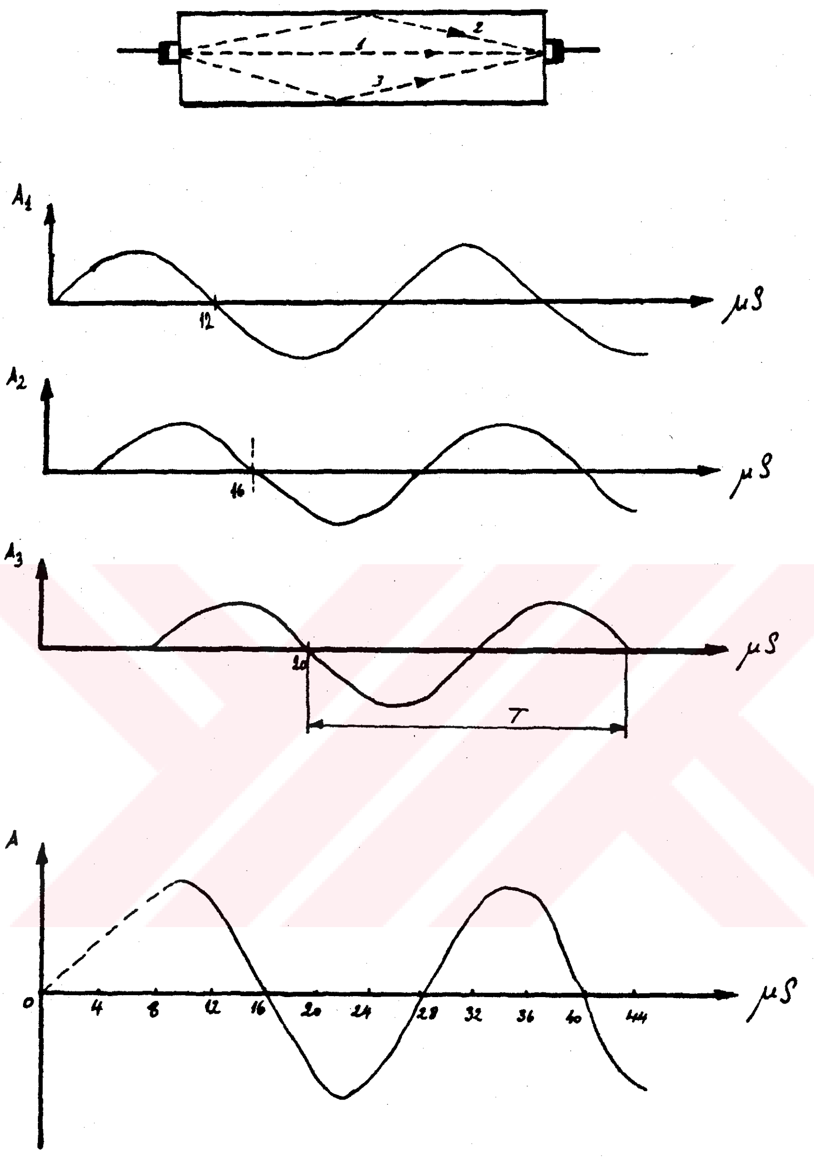
Figure.3. Forms of waves.

here with the condition that the sonic pulse can be recorded by the receiving amplifier.

2.3. The frequency of Ultrasonic Waves

For an exact measurement of the travel time, the pulse edges should be very sharp. This means high frequency. But in heteregenous materials only low frequencies can diffuse to acceptable depths, whereas high frequencies faint away rapidly. The solution of this problem is to find the optimum frequency. Frequencies between 20 to 200 kHz is acceptable. λ, the wavelength is in between 2-20 cm's for a concrete of V=4 km/s. Experiments has shown that frequencies between 40-50 kHz (λ = 10 cm) are very appropriate.

When the distance between transmitter and receiver is extended the amplitude of the front edge of the pulse decreases. The reason for this are the waves that are reflected from the particles on the way or from the sides. The reflected waves that reaches the receiver at different times and with a phase difference causes interferences. (Fig.4). In the figure three wave trains with equal amplitude with a phase difference of 60° are shown. If these waves are superimposed, a curve train is obtained but the front edge will approximately be half of the sharp slope of the later oscillations.



$A = A_1 + A_2 + A_3$

$T = 24 \mu S$

Figure 4. Three wave trains with 60° phase difference.

3. TESTING OF CONCRETE.

3.1. Effects on the Travel Time:

The measurement of travel time can be effected by the following factors:

a) The widthwise dimensions of the tested material

b) Existence of steel.

c) Moisture in concrete.

a) Sound velocity means the longitudinal waves as described in 2.1. . However these waves can occur only if the width of the sample is larger than the wavelength. It is almost always in this way. Otherwise for thin rod shaped samples,

$$V = \sqrt{\frac{E}{g}} \quad \text{is valid.}$$

b) Effects of parallel steel rods has been examined by Jones and Pohl.(5) It is shown that, sound velocity is affected by steel rods to the distance of 6 to 8 cm's. Value of the V_L increases because the sound velocity for steel is approx. 5 km/s, which is greater than that of concrete. To give reliable correction values here is naturally difficult. But usually the adherence between steel and concrete is so weak that the effects of steel is not even noticed.

c) Sound velocity is also affected by moisture. For instance for a little hole inside sound velocity increases from 340 m/s to 1500 m/s when it is filled by water. (5). Fig 5. shows the dependence of velocity to % moisture.

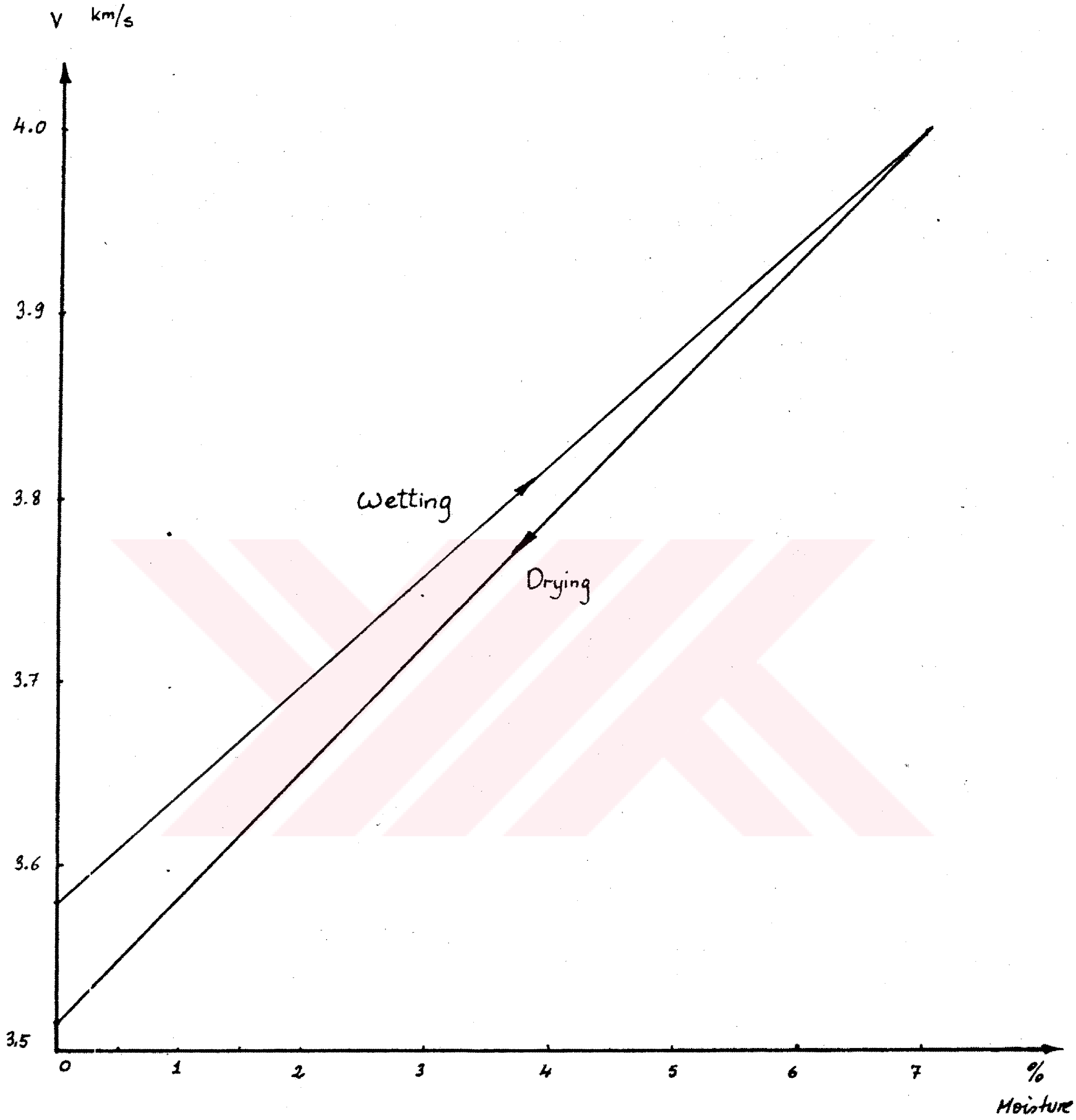


Figure 5. Effect of Moisture on sound velocity in concrete.

(GENSEL)(5)

3.2. Tests possible by Ultrasound:

The pulse velocity in a material depends on the material density and its elastic properties. These properties are in relation with the quality of concrete and its Compressive Strength. For this reason it is possible to have results about several properties concerning concrete by the help of velocity measurements.

3.2.1. Measurement of inhomogenities:

The measurement of the hole volumes, or cracked parts in a concrete sample which contains grains of gravel is made by the method in Fig.2., and is successful if the flawed part is larger than the wavelength. On the other hand flawed parts at the surface can be located by the indirect method, (See fig.), as in Fig.6. In this way for the travel times measured according to the path length, a linear line does not occur because the sound velocity at the flawed region is relatively low. (4),(5).

3.2.2. Measurement and calculation of crack depth:

The same method can be helpful to determine the location of a crack,by the rapid jump on the travel time curve as in Fig.6. The depth of this crack, can be determined by the time t_2 , which is the time needed by the longitudinal wave to turn around the crack.(Fig.7.). In all cases one should know the time t_1, for the same path S , at an unflawed part of the concrete sample. The crack depth " h " is given by a simple relation.

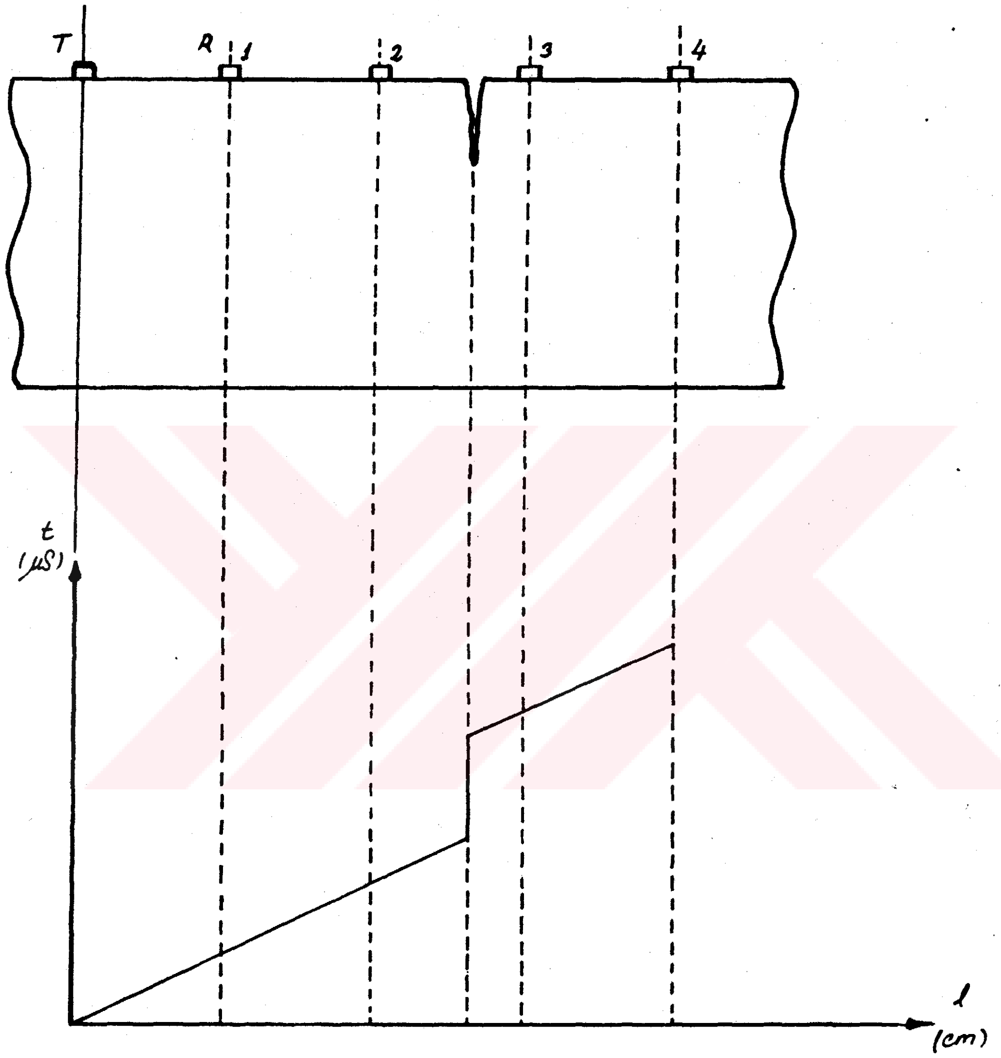


Figure.6. Location of surface crack in concrete by indirect method.

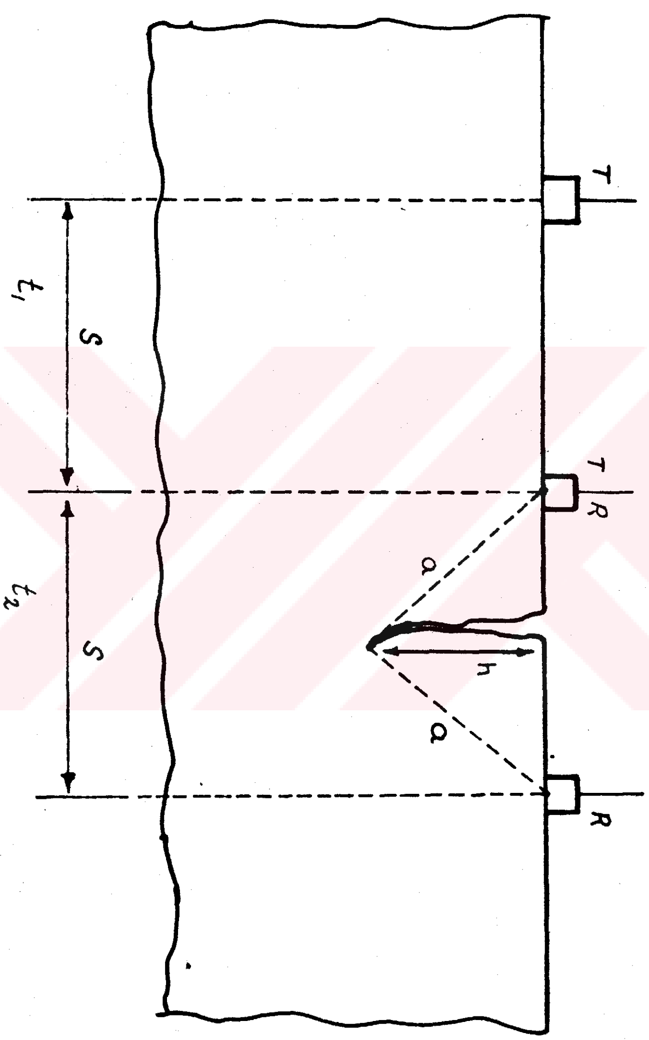


Figure.7. Schematic for calculation of Crack Depth.

$$h = \frac{S}{2} \sqrt{\left(\frac{t_2}{t_1}\right)^2 - 1}$$

(See app.)

e.g. Let the distance S be 40 cm, t_1 = 40 uS, t_2 = 50 uS. Then,

$$h = \frac{40}{2} \sqrt{\left(\frac{50}{40}\right)^2 - 1} = 20 \sqrt{1.25^2 - 1} = 20 \times 0.75$$

$h = 15cm$

3.2.3. Effects of content changes by time:

a) Hardening of Concrete:

The beginning of hardening of concrete can be determined easily by measuring the travel time. A slight increase in velocity is noticed, by the beginning of hardening.(4). In figure 8., the change of longitudinal velocity by age is plotted. This curve is obtained by testing the longitidunal velocity in test cubes and immediately afterwards crushing the cubes in a cube crushing machine. (4). It will be seen that there is initially a rapid increase of the wave velocity at early ages and then a more gradual increase at the greater ages.

b) Effects of freezing and fire:

Freezing causes the velocity to decrease. (5). In the sam way sound velocity decreases by effects of fire. In figure 9. the change in velocity

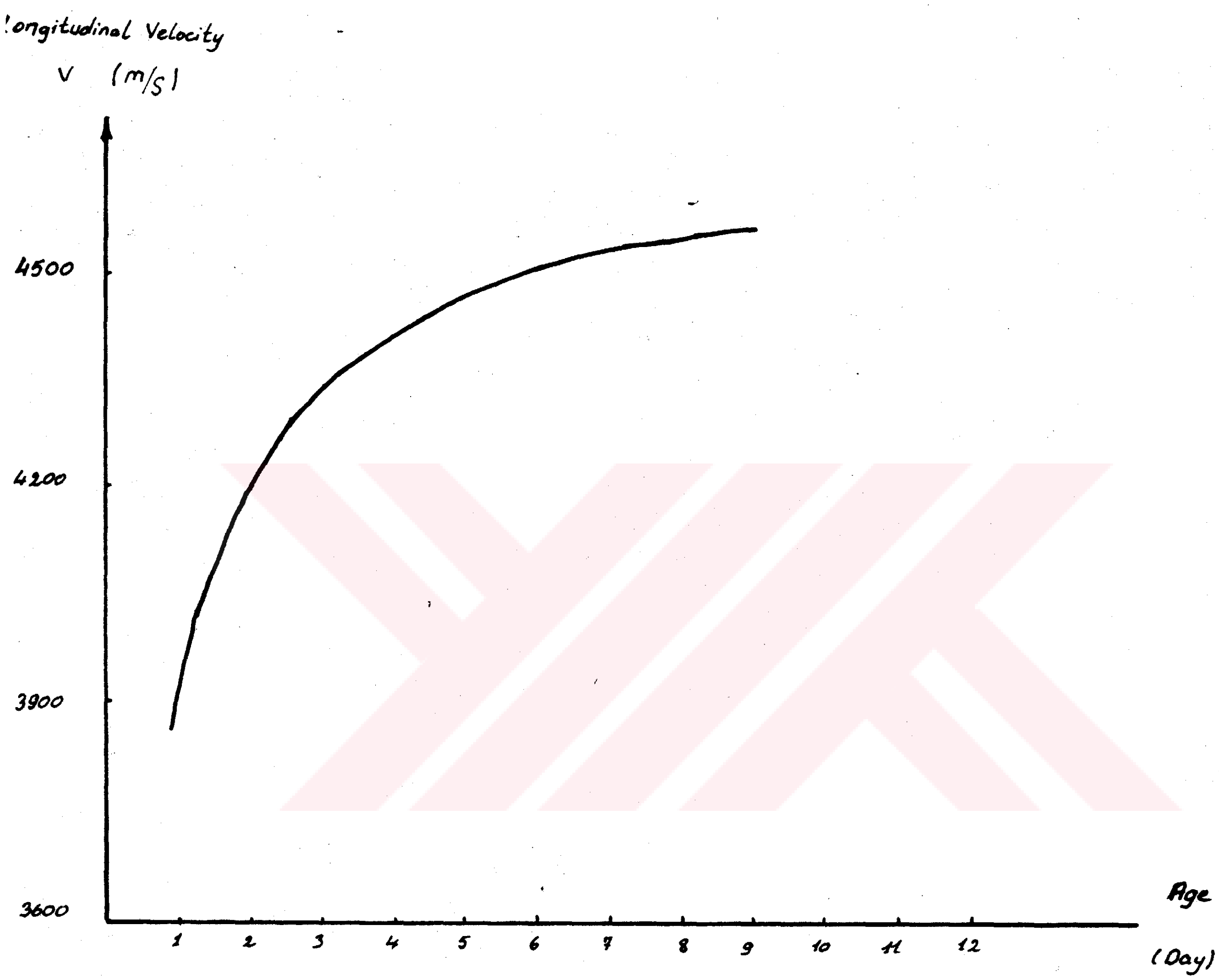


Figure.8. Change of Longitudinal Velocity by age in concrete.(5,4)

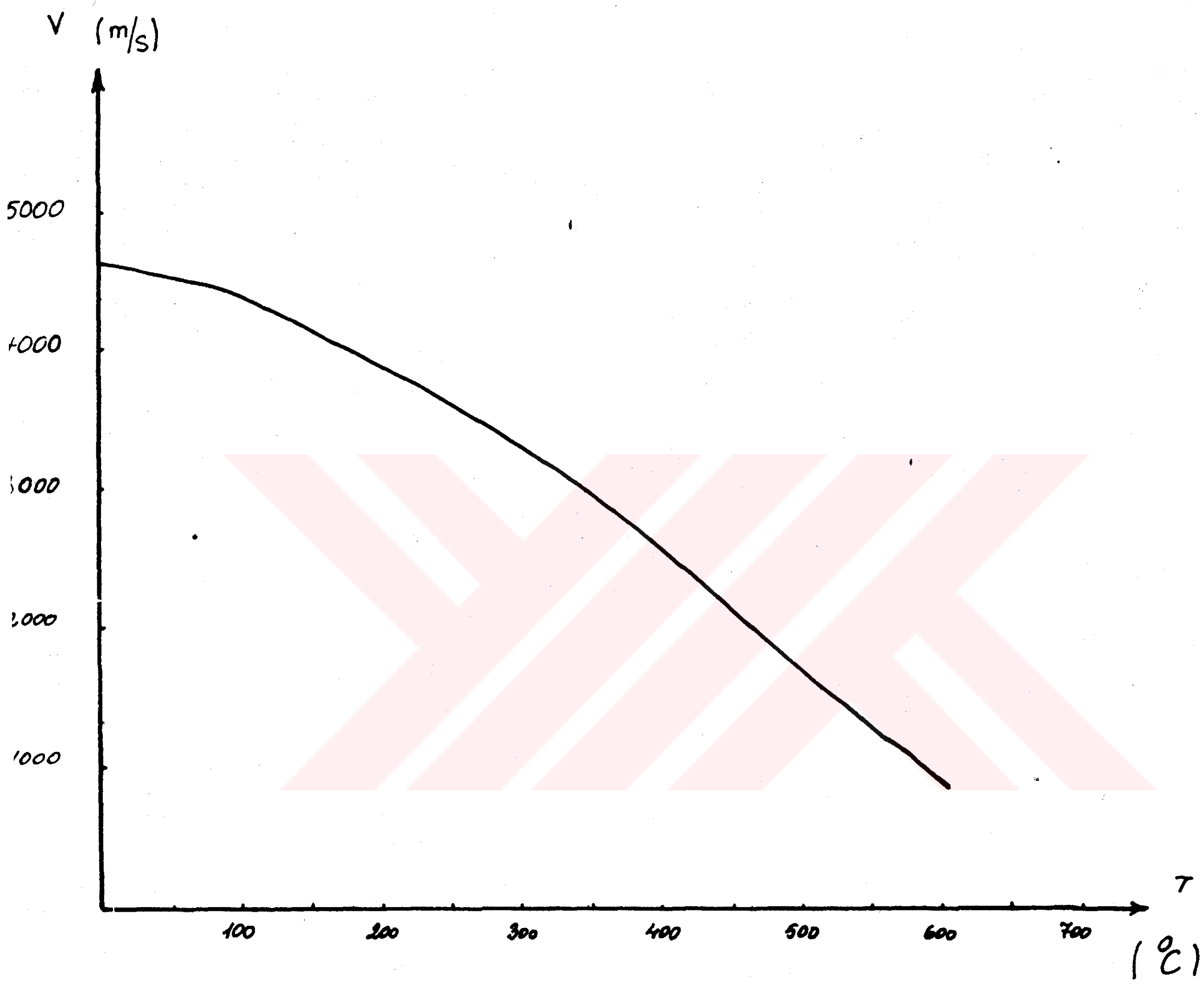


Figure.9. Change in velocity by effects of fire. (Watkey,5)

by fire effects is plotted.

3.2.4. Determination of Elasticity Modulus:

Dynamic Elasticity Modulus of a material under test is solved from longitudinal wave velocity, and by substitution in the previous equation;

$$E = V^2 \cdot \rho \cdot \frac{(1+\mu)\cdot(1-2\mu)}{1-\mu}$$

Since Elasticity is proportional to the square of the velocity, then velocity should be measured as exact as possible, because the error in E increases two times. Other than velocity, density ρ , and Poisson Coefficient μ , should be known for the determination of Elasticity. Poisson Coefficient and density are accepted to be related with age and moisture of concrete. Poisson coefficient is inversely proportional to the weight, age, and dryness of concrete. It is approximately 0.5 - 0.1. For a normal, 30 days old concrete $\mu = 0.25$ with a reliable approximation.(5)

3.2.5. Compressive Strength:

Different authors has given several formula for the relation between Elasticity modulus and Compressive Strength according to the sound velocity.(5) But generally the following formula were proved to give sufficient results.

$$\text{COMPRESSIVE STRENGTH} = a.\ V^4$$

$$= 1/k\ .\ E^2 \qquad (5)$$

Here a and k cofficients can have very different values due to the kind and quality of aggregate, age of concrete, and water contained. For this reason for every different sample that is being tested it should be determined especially. One can say that, without knowing the contents of concrete or reference samples, it is not possible to determine the exact strength of the concrete . But on the other hand, if sequental tests are made on the same kind or serial concrete samples, then very sensitive results can be derived.

4. GENERAL RESULTS AND PROBLEMS ON CONCRETE TESTING

As a summary, checks on defects and strength are of great interest both in large concrete structures as well as in mass production on prefabricated units. The intrinsic inhomogeneity limits the frequencies which can be used for the purpose of testing to 100 kHz and less where probing distances exceed 1 m. To obtain a sharply collimated beam the transducer used for concrete would have to have a diameter of approximately 350 mm at 100 kHz. A transducer of this size could be obtained by a mosaic of crystal plates. But uniformcoupling would be very difficult particularly where the surface of the specimen has to be scanned over rather large areas. In practice therefore probes which are not much larger than the customary ones are usually used and thick oil, grease, coupling paste containing water, glycerine, kolin slurries, soft soap and similar substances are used for coupling. Occasionally the probes are also attached by means of plaster for instance where observations over a long period are required.

The contact face naturally radiates other wave modes besides longitudinal waves of appreciable density. Astrong surface wave can always be assumed, which results in many disturbing echoes of uncontrollable direction and origin being obtained with the echo method that this

this technique can rarely be used. As a rule therefore one uses two probes with pulse transmission. The fastest wave received in this way is then always the direct longitudinal wave as stated before. (Fig. 10.). This is followed by the transverse and surface waves which depending on the shaped of the specimen, and may be disturbed by the reflected longitudinal waves. (1)

For quality tests on concrete one measures primarily the longitudinal acoustic velocity. (2.1.) Using the associated formulas one can calculate from it , Young's Modulus if poisson's ratio is known. This however, varies greatly. (3.2.4.). 0.1 to 0.2 for dry old concrete; 0.3 to 0.5 for wet ones. (0.5 for liquids) (1)

In practice however Young Modulus is less important as a criterion of the quality of a given concrete than the compressive strength and flexural strength.

4.1. Rules related with Acoustic Velocity and Quality of Concrete:

After setting, the compressive strength is proportional to the acoustic velocity, as confirmed by measurements.

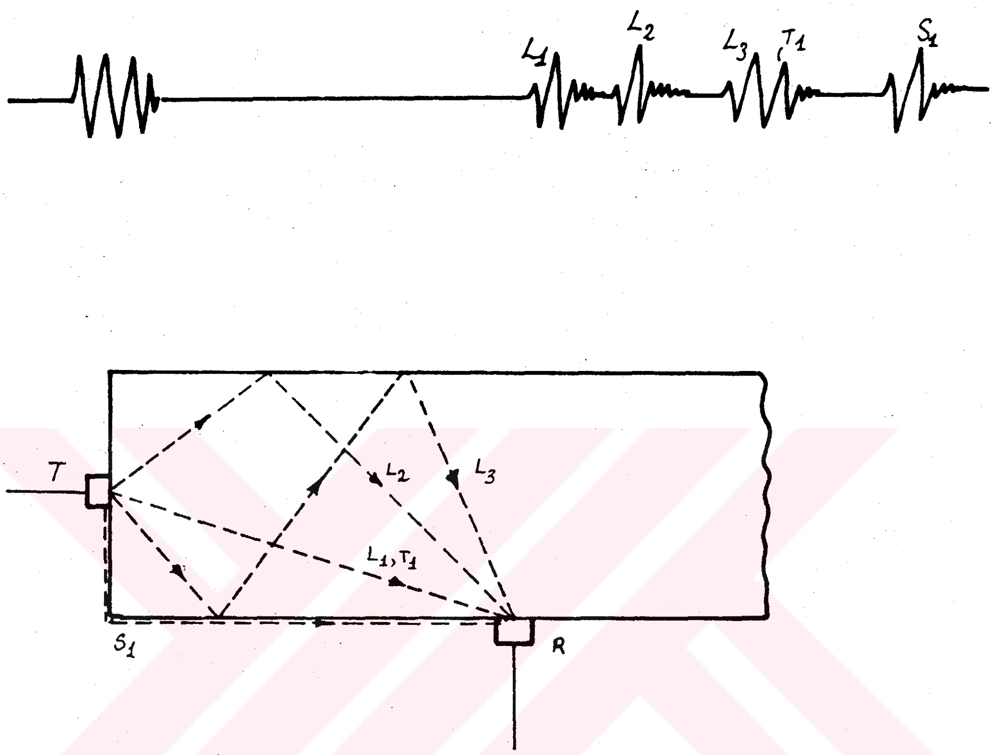


Figure 10. Testing concrete by pulsed sound transmission, and detection of Longitudinal, Transverse and surface waves.

Where only rough measurements are of interest, it is believed that none of the many influencing factors, setting time, mix, (i.e. cement, sand, aggregate ratio by weight), type of aggregate, water cement ratio, moisture content etc. need be taken into consideration.

The following gradient can serve as a rule: (1)

LONGITUDINAL VELOCITY		QUALITY OF CONCRETE
above	$4.6 . 10^3$ m/s	VERY GOOD
	3.6 - 4.6 km/s	GOOD
	3.0 - 3.6 km/s	MODERATE TO QUESTIONABLE
	2.1 - 3.0 km/s	BAD
below	$2.1. 10^3$ m/s	VERY BAD

Approximately 3.6 to 4.0 is regarded as the lower limit of a still acceptable quality. Figure 11 gives some values measured by Jones and Gatfield on various concrete mixes with river gravel as aggregate. Both the type and quantity of aggregate are thought to have a decisive influence on the acoustic velocity so that deductions concerning the strength would be permissible only if the content of aggregate is constant and known.

4.2. Other results:

The reinforcement has a slight influence on the acoustic velocity only if sound beam happens to be coaxial with very thick reinforcing steel rods above 20 mm in diameter. (3.1.b.). This increases the velocity slightly, which may simulate a slightly greater strength.

During setting , both the velocity and the strength increase rapidly and proportionally. Measurement of the velocity thus offers a possibility when concrete components are mass produced, e.g. also pre-stressed components, rapidly determining the instant when the strength is high enough for the shuttering and the prestressing to be removed, or transporting the component. Both are of economic interest.

The velocity follows the compressive strength where it has been reduced by freezing and thawing periods.

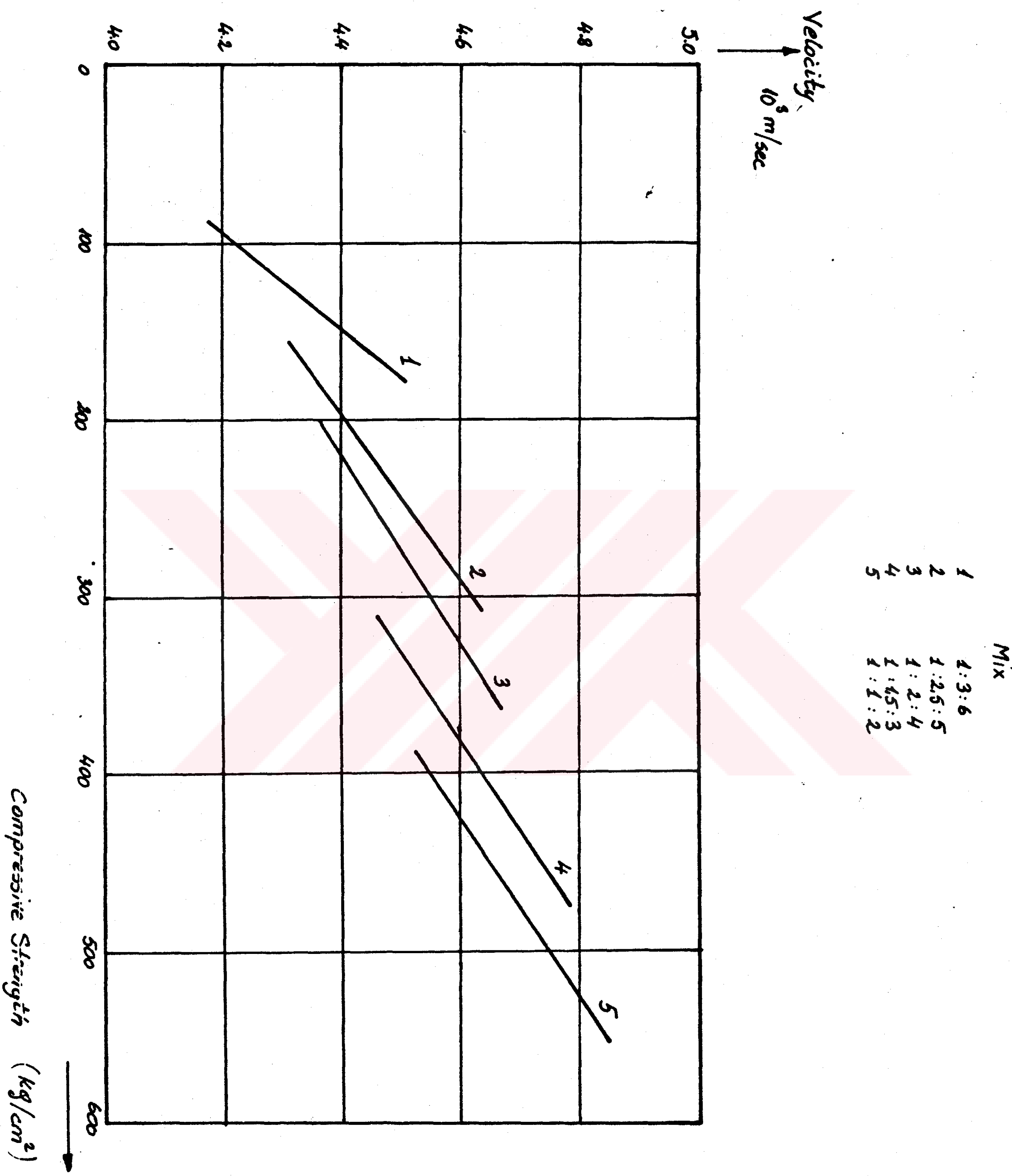


Figure11. Correlation between Longitudinal Velocity and Compressive strength on concrete specimens with different mixing ratios.

Cracks in concrete structures (3.2.1.) were first determined by means of Ultrasonics in 1939's , on reinforced concrete beams by the intensity method. The disturbances by interference while using continous sound are now avoided by pulsed sound transmission. By this means it is possible to deduce the presence of defects from the decreased intensity, without being able to determine the depth on large concrete structures accessible from both sides, such as dam walls and storage tanks . But it cannot be concluded that these effects are cracks, shrinkages or inclusions of foreign bodies because the areas poor in cement, strongly weaken the sound. If there is a defect in the sound path when sound transmission is used, the acoustic velocity is also changed by the detour around the flaw.

Surface cracks which are not visible to the naked eye or whose depth has to be measured are determined as follows: (3.2.2.)
One measures the transit times between a number of measuring points on the surface arranged along a straight line from the fixed transmitter. If the distance is plotted against it, as in figure 12, a sound-concrete structure gives a straight line whose gradient corresponds to the uniform acoustic velocity. Cracks transverse to the measuring line, force the Ultrasonic waves to make detours. This increases the transit time the

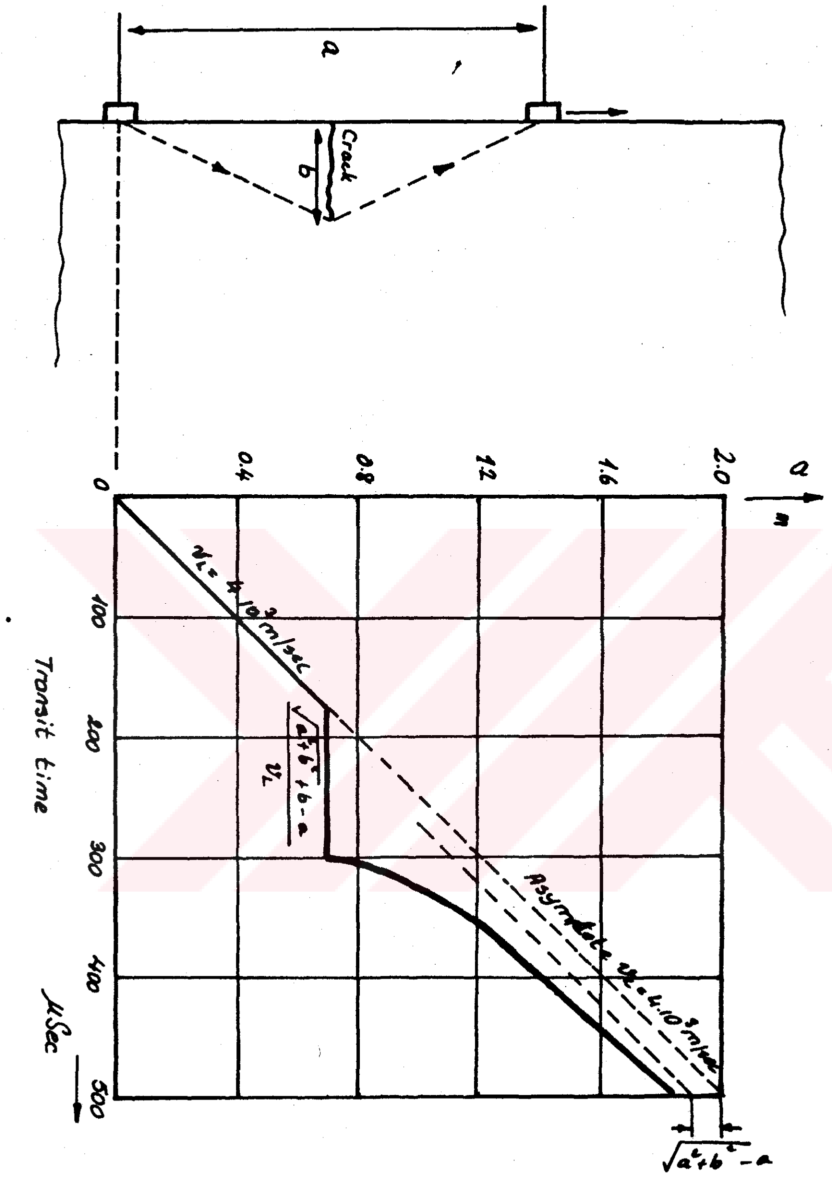


Figure 12. Propagation Diagram according to Dawance(1), with crack in path of sound wave. a= 0.7 m, b = 0.4 m, $v_L = 4.10^3$ m/s.

deeper the crack. The curve shows bends from which one can deduce the position and depth of the crack. This presentation also enables one to recognise whether the layers of different strength are superimposed or whether the layers are not bonded satisfactorily, e.g. as a consequence of casting errors. It is also possible to calculate the crack depth.(1),(5).

5. THE PROBES

The probe contains the Piezoelectric Transducer which converts high frequency voltages into Ultrasonic waves. In a normal probe these waves are normal to the radiating surface, i.e. they enter the surface of the specimen at right angles. In the most simple application the piezoelectric plate is wetted slightly with a liquid and pressed against the surface of the test piece,the electric pulse being placed on the metallized back of the plate.

If no particularly sharp pulses are required the crystal plate wetted with oil can be pressed from the inside against the flat bottom of a metal cup so that it radiates through its bottom into the test piece. For most practical applications, particularly in the case of single probe operation, the transducer plate can then be used directly or via an intermidiate layer for making contact with the test piece.

The damping body in figure 13. has several functions. In order to damp the oscillations of the crystal sufficiently its acoustic impedance should be high. It could consist of solid and hard materials such as porcalain. It should also absorb the waves which cannot be prevented from entering it, not to produce interfering echoes. The acoustic impedance can be increased by admixing metal powder and the absorbtion can be

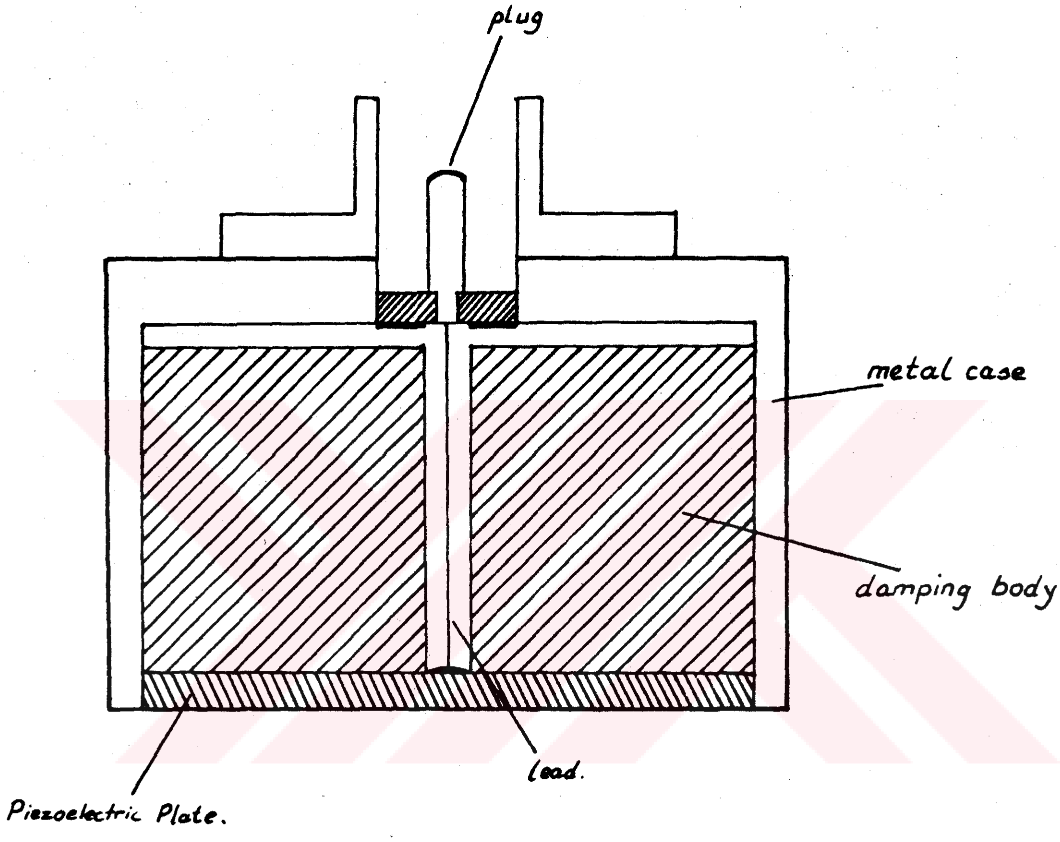


Figure 13. Construction of a normal probe.

increased by adding finely ground materials. If the content of admixed metal powder is high, the damping body can attain sufficiently high electrical conductivity for the high frequency pulse. In the case of quartz the electrode can be omitted but the damping body must be mounted insulated. However Barium Titanate, with its high dielectric constant definitely requires a metellic electrode directly on the PE plate. (1)

The problem of matching the transducer to the material of test piece by means of intermidiate layers of gradually changing acoustic impedance can be solved with several layers in which the acoustic impedance decreases from layer to layer. Ideal matching would mean maximum sensitivity without lengthening the pulse by internal reflections. If only single layer is used, its thickness should be a quarter wave length and its acoustic impedance the geometric mean of the acoustic impedance of the continuing materials, that is,

$$\sqrt{W_1 W_2} \quad .$$

Most probes have circular radiating surfaces with diameters of approx. 5 to 40 mm. Diameters larger than 40 mm are not suitable for most test problems because of a corresponding flat contact surface is not available. The disadvantage of smaller diameters, which is the case in low frequencies for large λ/D values, is the greater radiation of lateral transverse waves and surface waves, (Fig.14), as well as greatly reduced sensitivity.

6. PIEZOELECTRIC PLATE WITH PULSE EXCITATION

Adequate number of oscillations is particularly important when transmitting short pulses. In the echo method for example the length of the pulse may prevent the detection of flaws near the surface and pulses of minimum duration are therefore desirable. At high frequencies these pulses may have a large number of oscillations. But on the other hand the damping of most materials increases with the frequency. It is therefore necessary to generate and transmit pulses at frequencies which are not excessively high and with a minimum number of oscillations. Even it may be useful to produce complete aperiodic shock pulses.

Let us consider various types of electrical pulses and investigate how the piezoelectric plate behaves in these cases. First let us take an alternating voltage train with 10 oscillations at the characteristic frequency of the plate. At the beginning and at the end this train suddenly disappears. Because of its inertia and the elastic forces, the plate tends to resist any sudden c anges and smoothes them out at the beginning and at the end of oscillation by build up and decay pocesses. The actual oscillation of the plate is therefore composed of the motion of an

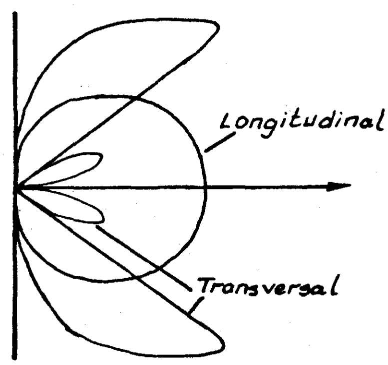


Figure 14. Directional characteristics of a very small radiator in a solid body, calculated by Roderick for large λ/D value. $\mu = 0.25$.

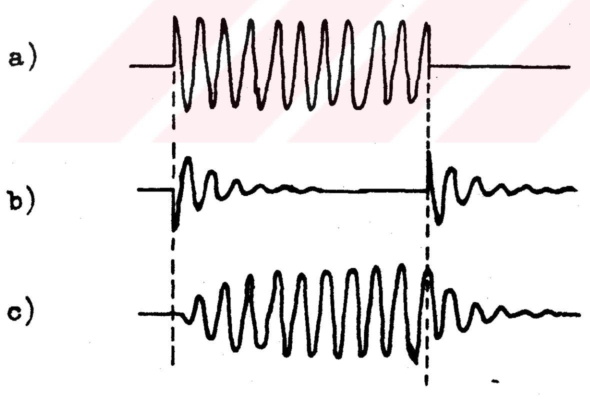


Figure 15. Excitation of a piezoelectric plate.

a) Alternating voltage train of an inertialess plate, b) Transient oscillation of an actual plate, c) Oscillations occurring in the actual plate, i.e. sum of (a) and (b).

inertialess plate subjected to the influence of voltage plus the transient oscillations. In figure 15 curves (a) and (b) should therefore be added so that the actual oscillation of the plate is obtained in (c). I have observed this phenomena during experiments.

Since short pulses are particularly important in non-destructive testing, the basic rule concerning piezoelectric plates operated as transmitters, by a more rigourous treatment of the plate which make it possible to construct correctly the pulse of the sound pressure for arbitrary exciting voltages by using a rather simple method exists.(1),(5)

If an arbitrary voltage is applied to a piezoelectric plate, sonic pressure waves radiate simultaneously from both surfaces. They travel into the plate as well as into the materials coupled to it externally, but inside the plate their phase is opposite to that outside. Their amplitudes depend on the acoustic impedances of the materials concerned. If the waves inside the PE plate strike the boundary, the rules apply for their reflection and refraction, together with the rule of phase reversal at reflection on sonically softer material. Further they are superimposed upon each other without distortion.

Let us assume a short square wave pulse in a thick plate so that the delay in the plate exceeds the duration of the pulse. Further let us take the simple case of a reflection free boundary on both sides, i.e. the acoustic impedances are equal, $W_1 = W_2 = W_3$. The internal waves pass without any impedance through the opposite faces and completely leave the PE plate. Thus outside the plate two identical opposing pulses follow each other at an interval determined by the delay in the plate. In the case where the plate on one side borders the air, and the matching on the other side is no longer reflection free , e.g. $W_2 / W_1 = 0.25$, this results in a sequence of pulses which follow each other at the delay distance of the plate. The second pulse is always twice as large as the first and the later pulses decrease in a constant ratio. (Fig.16,Fig.17.)(1)

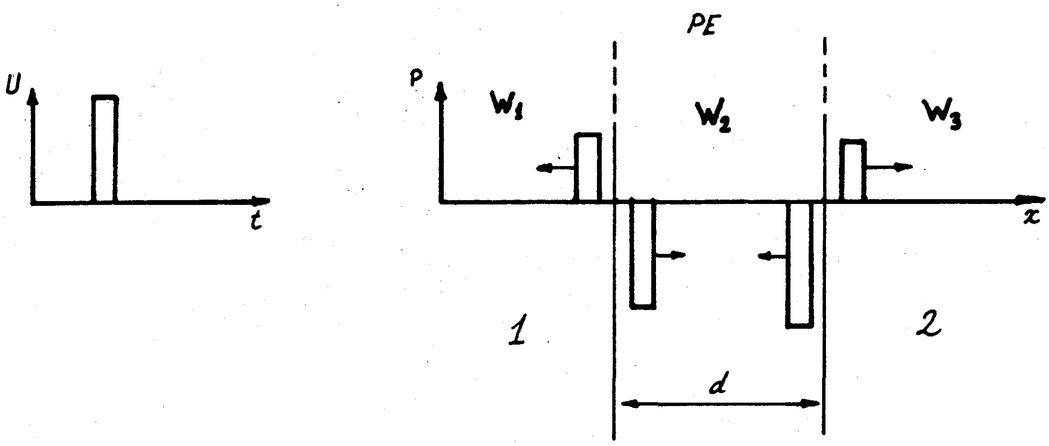


Figure. 16. Acoustic Pressure waves, excited by the voltage U as a function of time, along the axis of a transducer between two materials 1 and 2.

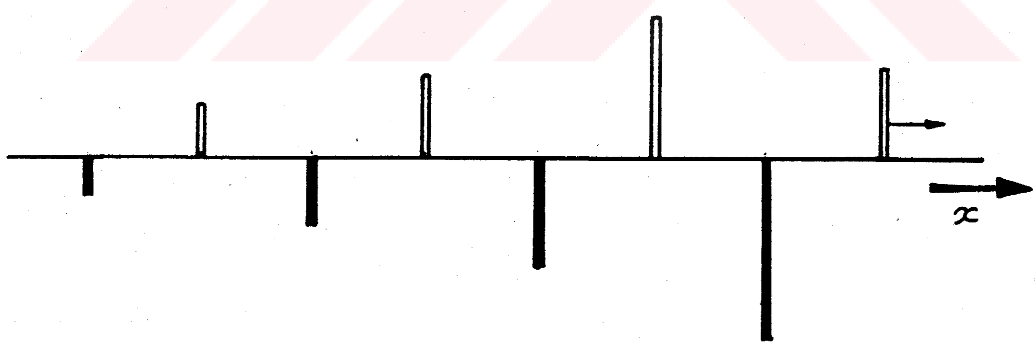


Figure 17. The pulses in one direction with sonically soft matching on opposite side. The second pulse is twice as large as the first.

II. THE ULTRASONIC TEST INSTRUMENT

The Ultrasonic Instrument has been developed for non-destructive testing of coarse grained materials such as concrete and rock, and is also capable of measuring velocities in gases. It employs the pure transit time method and with a simple modification can easily be adapted for measurements in metals. It contains transistors and integrated TTL-type circuits. The transit time of the Ultrasonic pulses through the material under test is read on digital LED displays. It is operated by mains or can be operated by a battery if desired.

1. Technical description of the circuit:

A block diagram of the instrument is shown in figure 18. A pulse generator produces needle pulses at adjustable regular intervals of approximately 1 second. This pulse triggers the transmitter oscilator which produces the reqired resonance frequency for the transmitting transducer, which converts the electrical pulses to mechanical pulses. This trigger pulse is fed simultaneously to a monoflop for delaying purposes and calibration of the instrument. One of the delayed pulses namely the reset pulse, is sent to the decade counters in order to clear the result of the last measurement in the preceding second. The other

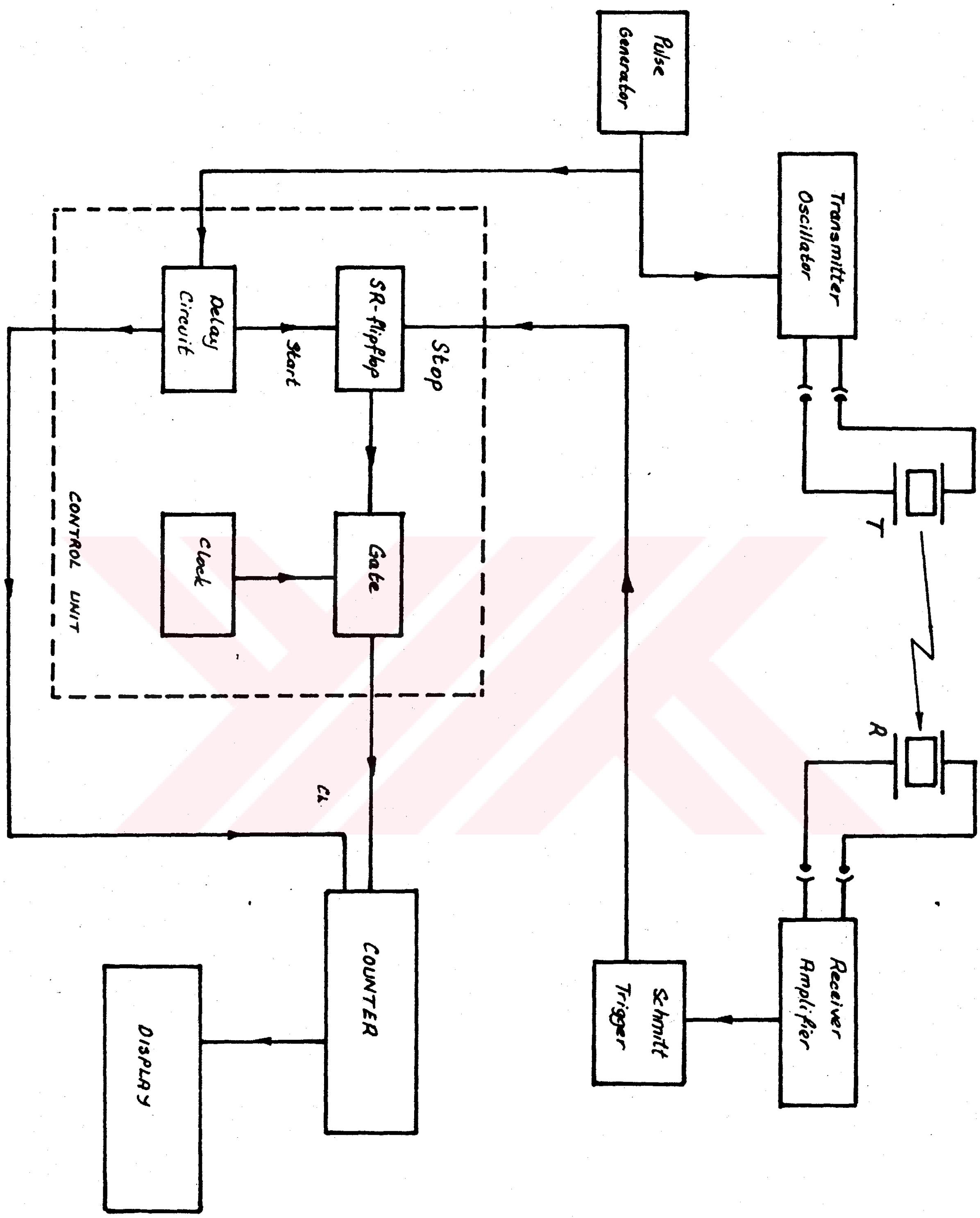


Figure 18. Block diagram of the circuit.

delayed pulse is fed into an SR-flipflop which is set by this pulse. The output enables the gate and 1 MHz crystal controlled clock pulses are applied to the decade counter and counting starts. Ultrasonic pulses after travelling through the test specimen are reconverted to electrical pulses by the receiving transducer. They are amplified by the receiving amplifier and the first edge triggers the Schmitt-Trigger circuit of which the output reset the SR-flipflop. Thus, the gate closes and counting ceases.

Therefore the interval in which this memory is set and reset is identical with the transit time of the ultrasonic waves travelling through the specimen. The number of the counted pulses indicates the transit time in microseconds. The accuracy is theoretically 10^{-5}.

2. Pulse Generator:

The function of the pulse generator is to produce needle pulses at regular intervals of approximately one second. The test cycle begins with these produced pulses. It triggers the transmitter oscillator and a monoflop simultaneously. In this circuit transistor couples BC107 and BC177 show unijunction characteristics if connected as in the figure 19(a). The time constant of the needle pulses i.e. the interval, is determined by the resistors R_1 and R_2 and charging capacitor C. Resistors R_4 and R_5 forms the bias voltage for T_1. When the capacitor voltage is high enough, T_1 turns on, and turning on T_2 at the same time, producing a pulse to derive switching transistor T_3, 2N2222. The voltage that T_1 turns on is called the peak voltage, V_p. T_1 and T_2 together shows a negative resistance characteristic. Because the current through transistors increase while the voltage across them drops. (Fig. 19(b)). Therefore the values of R_1, R_2 and R_3 must be so chosen that the load line intersect the V,I characteristics of the UJT at negative resistance region for recovery purposes. Otherwise the UJT will only pulse once and not recover. The bias voltage at the base of T_L is 5 Volts. When the transistors turn on, the voltage at this point drops

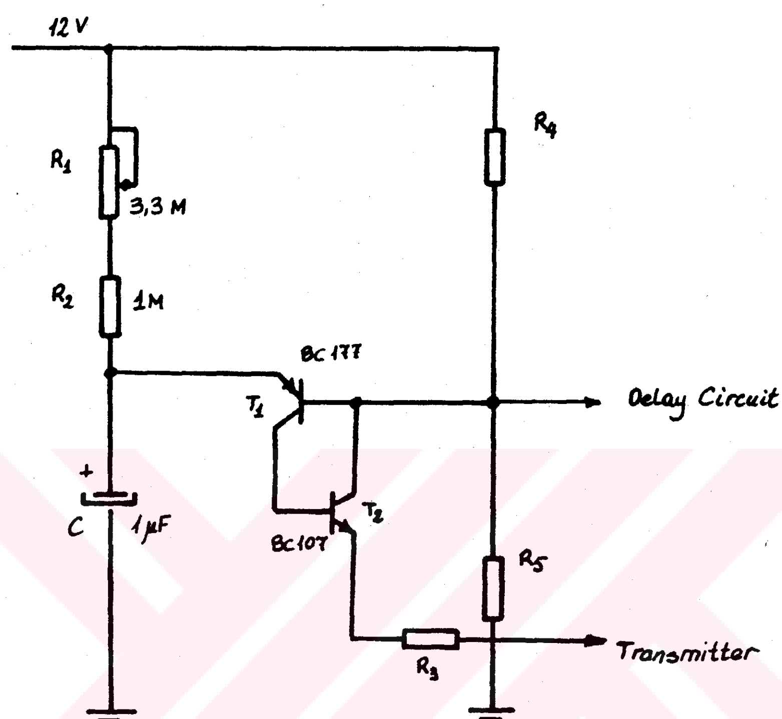


Figure 19(a). Pulse Generator.

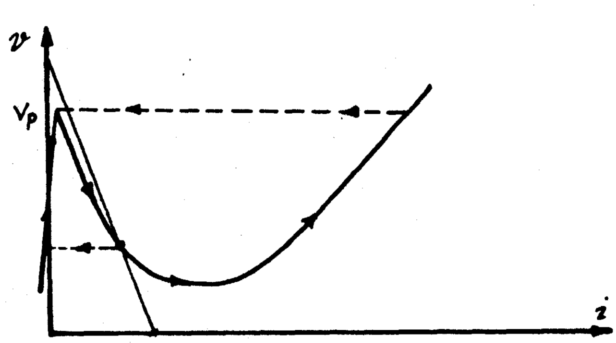


Figure. 19(b). Unijunction characteristics.

approximately to zero or ground level. The latter then, as a second output , is fed into the delay circuit, and the falling edge triggers the monoflop.

3. Control Unit:

The control unit consists of the delay circuit, SR flipflop, gate, and the clock circuit.

3.1. Delay Circuit:

This circuit has two functions. One is to produce pulses which are compatible to TTL circuits, the other is to give a delay to the triggering start pulse. (Fig. 20.a.) . It is basically composed of a TTL-type integrated circuit, namely 74121. The inputs of the IC is so arranged that B is held high and A_1 and A_2 are made short circuit and are connected as the input of the circuit and ready to be triggered by the falling edge of the trigger pulse. (See App.)

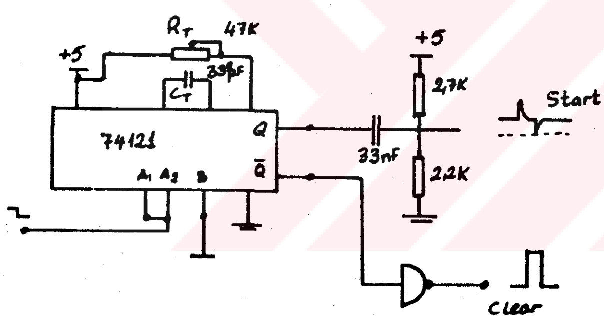


Figure 20(a).

The delay is given by C_T and R_T where R_T can be adjusted by a potentiometer, from 1 microsecond to 150 microseconds. The purpose of the delay is to make it possible to compensate the delays occurring from the transmitting and receiving crystals and the circuit itself, which is of the order of several microseconds. By adjusting this delay it is possible to calibrate the instrument for correct measurements. The other functions of the circuit is to set the flipflop and reset the decade counters. The Q output is fed into the SR flipflop as the start pulse, via the circuit in the figure while the inverse of the output, Q , is fed into the decade counters via an inverter, which originally is a NAND gate of 7400. The total delay of the reset pulse should be less than that of the start pulse because the reset pulse must clear the counter before counting cycle begins. This is the case because the delay of the start pulse through the whole circuit is totally twice as large as the reset pulse and of the order of 15 to 20 nanoseconds.

3.2. SR flipflop and the Gate:

The SR flipflop consists of two NAND gates of the IC 7400, connected as in the figure 20(b). The start pulse is obtained by the Q output of the monoflop as explained above, and is applied to the flipflop changing its output state to logic 1. The output is connected to a pursuing NAND gate which the other input is connected to 1 MHz clock generator. The output of the flipflop therefore controls

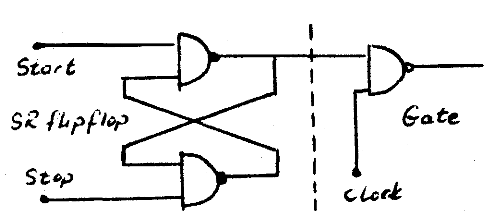


Figure 20.b.

the gate. When the output of the flipflop is 0, the output of the gate is 1. So when the output of the flipflop is 1, the output of the gate is pulsing. So the stop pulse reaching the reset input of the flipflop, the output state changes to 0, thus disabling the gate. The output of the gate controls the start and stop sequence of the counter by enabling and disabling the clock pulses to the counter circuit.

3.3 . The Clock Circuit:

The clock circuit is a crystal controlled oscillator which produces clock pulses for the decade counter at 1 MHz rate. They are controlled by the gate as explained above. The oscillator consists of two NAND gates of a 7400(fig.20.c.) Once the supply voltage is applied the oscillation begins. The crystal used is 10 MHz so the output is fed into a 7490 decade counter which is used as a divider to obtain a pulse period of 1 µs. The last two pulses of each ten is taken as the output and inverted for a suitable logical coupling to the gate. The frequency can be adjusted by a series capacitor.

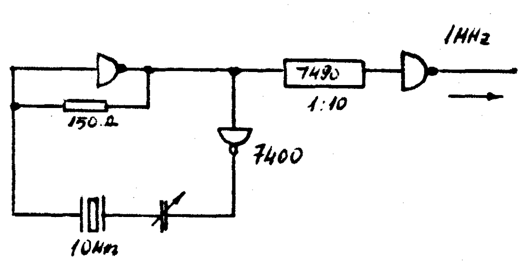


Figure 20.c.

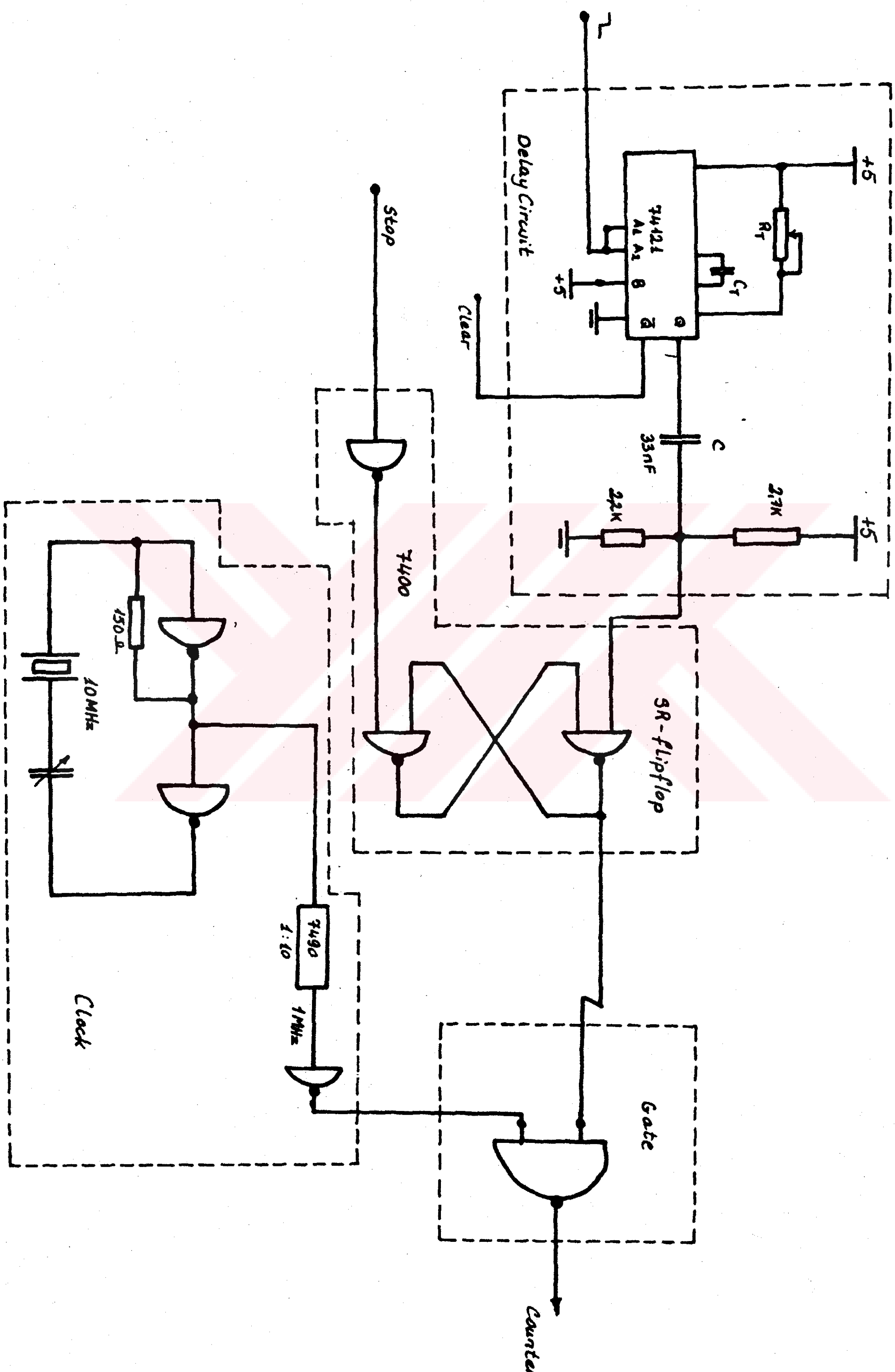


Figure. 20. CONTROL UNIT.

4. Transmitter Oscillator:

Transmitter oscillator is basically an astable multivibrator, triggered by a switcing transistor. (Fig.21) The operating frequency is the resonance frequency of the crystal, and it can be adjusted by a potentiometer. During experiments a 26 kHz, 0.1 W transducer is used. The excitation of the transducer is by d.c. pulses in a way suitable to its polarization. The duration of the pulse is long enough to produce 5 or 6 oscillations at the characteristic frequency of the crystal; which gives sufficient excitation to the crystal in this case. For different types of crystals and transducers, different transmitter circuits are needed. Other than this one a resonance a.c. oscillator can be developed or transmitting can be made by single pulse excitation. e.g. The transducer used during experiments was not suitable for single pulse excitations. This is a simpler but a more rigorous treatment but will give better results in the case of special transducer used for the purpose of testing concrete. Inthis case the crystal is treated by a shock pulse, the crystal surface hits the specimen and then a damping oscillation will be observed at the resonance frequency of the crystal. The suitable transducers are usually made of Barium Titanate or Lead Zirconate Titanate at a resonance frequency of 40-50 kHz. The low frequency introduces the problem of dimension both in thickness and diameter.

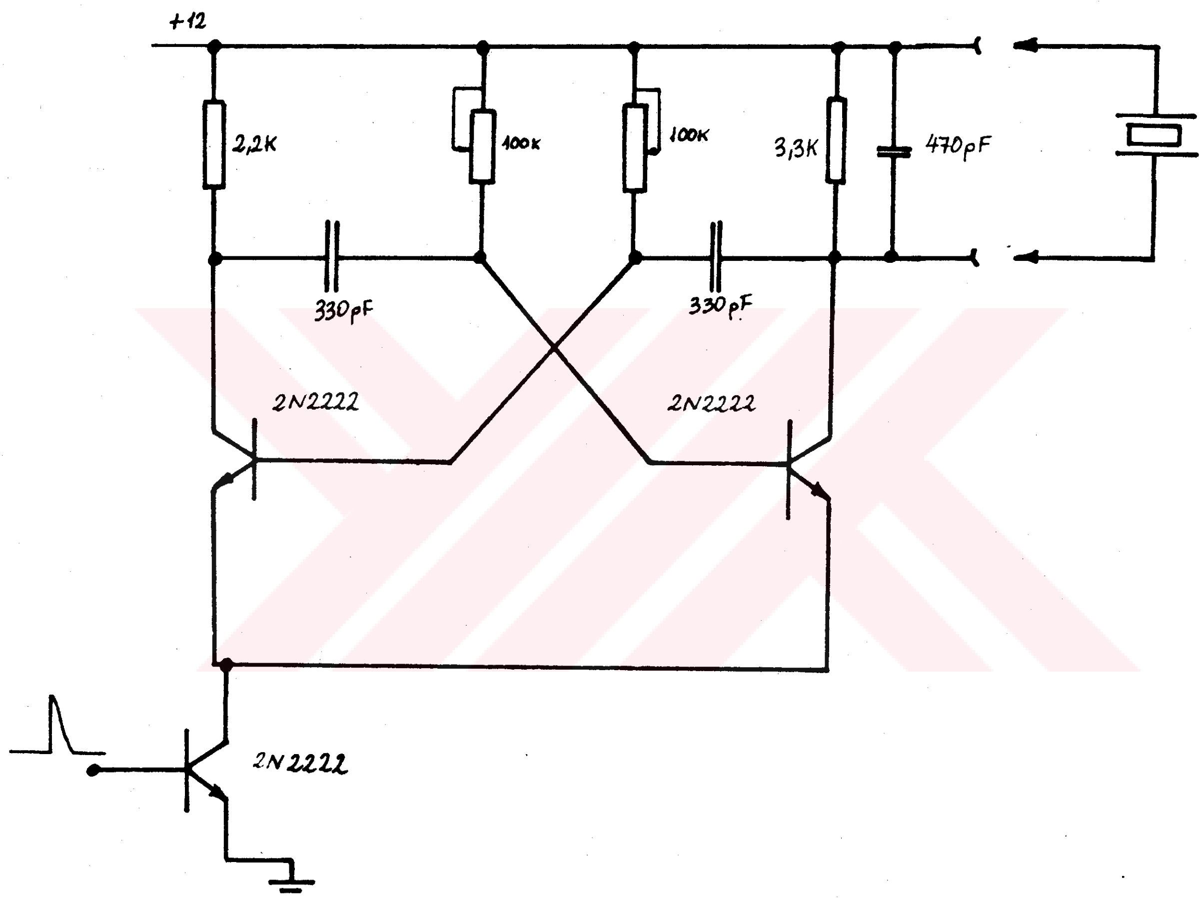


Figure 21. Transmitter Oscillator.

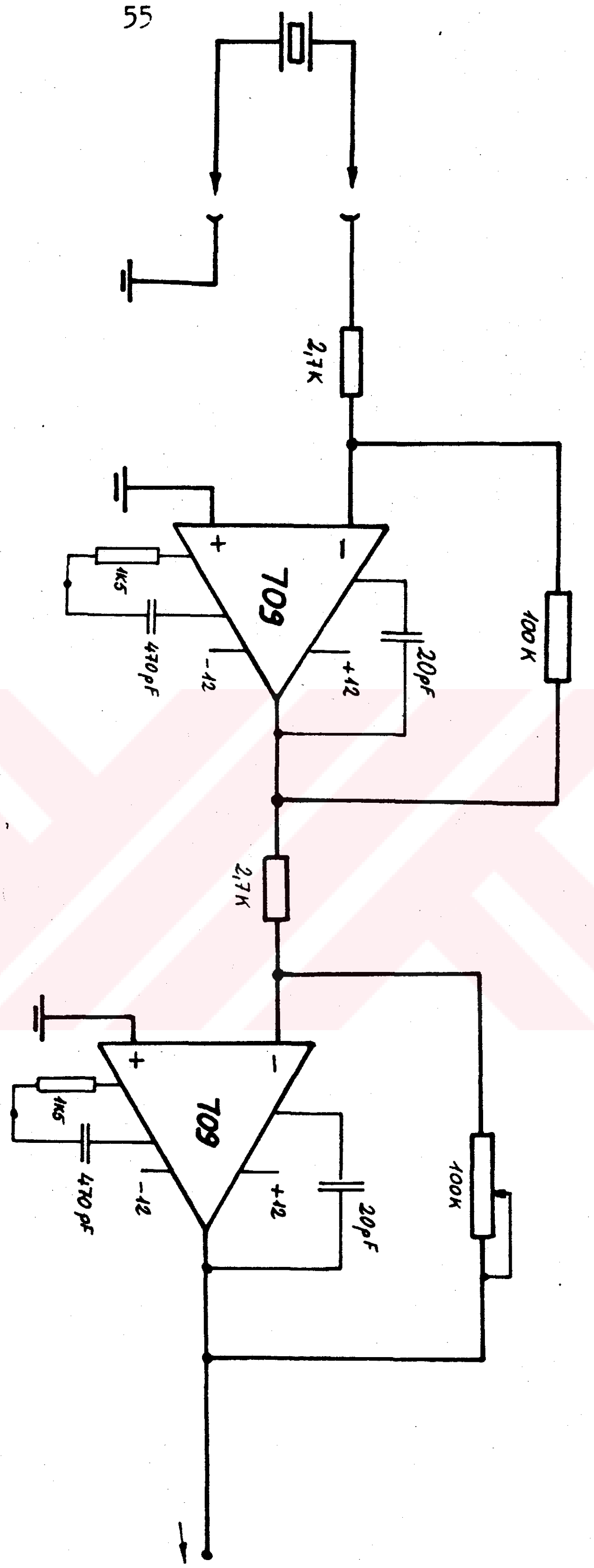


Figure. 22. Receiving Amplifier.

6. The Schmitt-Trigger:

The output of the receiving amplifier is applied to the input of the Schmitt-Trigger. The function of the circuit is to reset the SR flipflop, thus causing its state to change and stop the counting.(Fig. 23) The resistor values are so chosen that the Schmitt-Trigger begins operating at the threshold value of approx. 2 V. The amplifier has positive feedback applied between the collector of T_1 and the base of T_2 via R_2 and R_3. Since one of the transistors conduct at any time , the emitter potential is always positive with respect to zero line. i.e. T_1 is always conducting. When the input voltage rises above emitter voltage , T_1 is cut off. This causes the emitter voltage of T_2 to increase and the collector potential of T_1 begins to fall. These two effects turn T_2 rapidly on so that its collector voltage rises to its maximum value. The switching speed of the circuit is increased by adding the speed up capacitor C , which has a value of 100 pF.

7. Counter and Display:

Counter and display circuits consist of TTL components, the decade counters 7490, 7 segment decoders 7447 and 8448, inverters 7416 and LED numerical displays. (Fig.24.) The output of the gate is either logic 1 continously or pulsing as stated above and the 1 MHz pulses are fed into

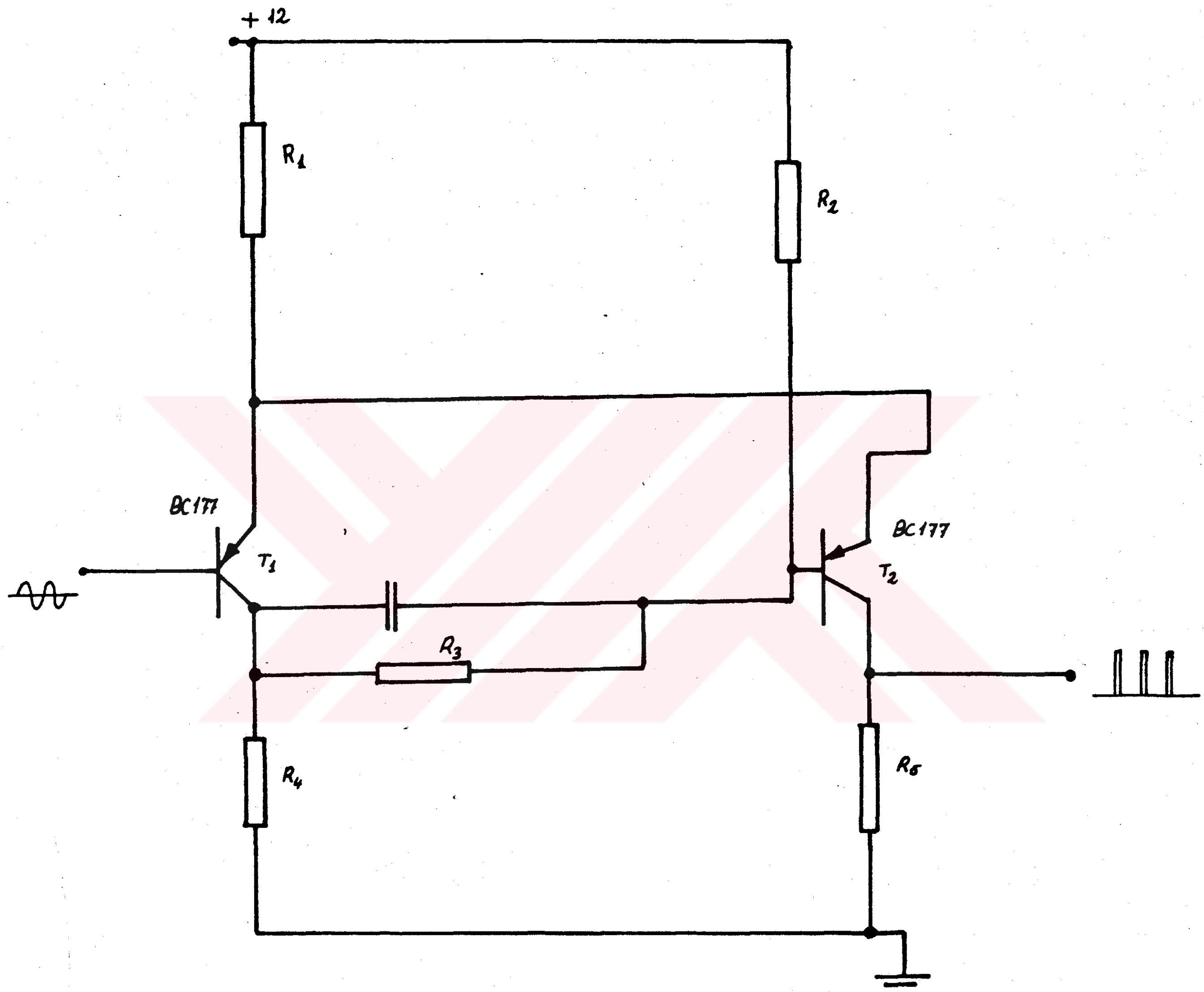


Figure. 23 The SCHMITT TRIGGER.

the input of the counter circuit. The last bit of the decade counter is fed into the next 7490 as the output pulse. 7447 is a BCD to seven segment decoder with open collector output. It is only convenient for common anode 7 segment displays, CQY91A, which are also used for indicating the transit time in the circuit. 8448 circuits are also BCD to 7 segment decoders but are suitable for common cathode displays. To fit these circuits with common anode displays, 7416 inverter circuits with open collector are added to the circuit and common anode displays are driven by 8448 in this way. (See App.). The function of the circuit is to count clock pulses, during set reset interval of the SR flipflop which corresponds to the transit time and the result is displayed. At the beginnig of every cycle this result is cleared by the reset pulse. Controls of 7490 is in the figure and in appendix R_{01} , R_{02} , and R_{91} , has been chosen for control purposes. The next reset pulse makes R_{o1} , and R_{o2} , logically high for a short time and this causes all the outputs to be 0 and thus the result is cleared. Just before the count command R_{01} , and R_{02} drop again to zero line which is the counting mode and new cycle begins.

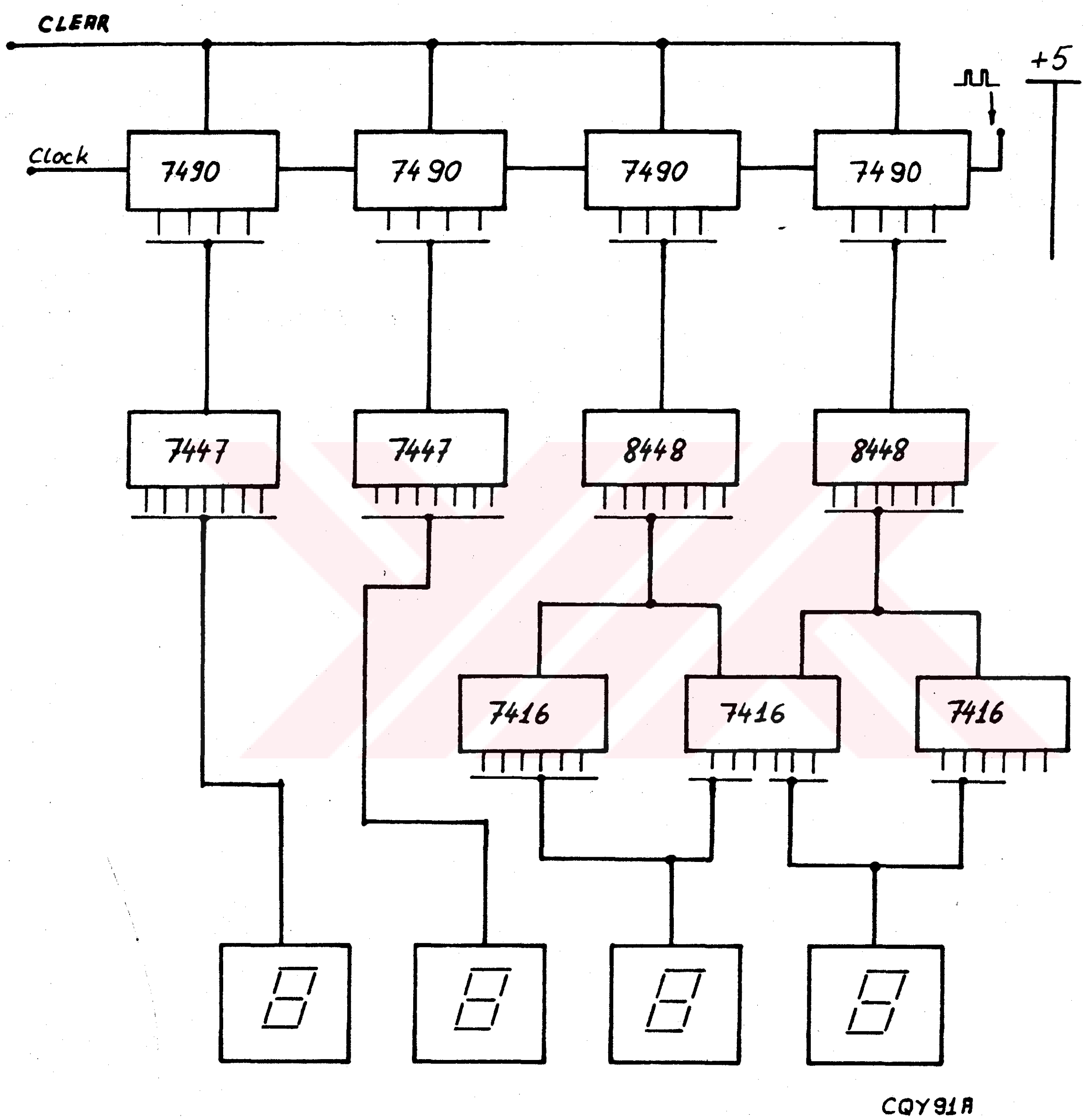


Figure. 24 COUNTER and DISPLAY.

8. APPLICATION RESULTS

8.1. Transit time measurements:

Experiments have been done in air by simulating the effects of the defects in concrete. Several transit time measurements have been done at different probe distances. Then a solid obstacle is placed on the travel path to simulate the sonic impedance and the transit time is measured again. The dimensions of the obstacle is 1 cm X 2 cm and 10 cm wide. The temperature is approximately 17 °C. The slight reduction in velocity was clearly observed. It was not possible to make measurements below 10 cm and above 80 cm. The measured values are given in Table I.

S: The length of travel path in cm.

t_1: The transit time measured in microseconds between two probes.

v_1: Sound velocity according to the measurements.

t_2: Time elapsed in the existence of an obstacle on the travel path in microseconds.

v_2: Effective (Reduced) velocity in m/s.

Plate Distance cm	Obstacle Distance cm	Time measured on the instrument µsec	Number of divisions on CRT ~
15	—	922	~ 9
15	5 cm	296	~ 3
15	7,5 cm	462	~ 4,5
15	10 cm	618	~ 6

Table II

9. Circuit Modifications and Descriptions for the higher powered Transducers:

The characteristics for the higher powered transducers are given in the appendix. The dimensions for 40 to 50 kHz Lead Zirconate Titanate or Barium Titanate transducer are 50 mm X 35 mm ∅. With this kind of a Transducer it is possible to make measurements in concrete to distances of more than 10 m.

It is better to excite a powerful transducer by a single pulse as explained in section II.4. The amplitude of this pulse is in the order of several hundred volts. The transmitter circuit which produces 300 Volt d.c. pulses is given in figure 25.a. The capacitor (0,25 μF) charges through R_1 (2MΩ) When the thyristor is fired by the trigger pulse fromthe pulse generator, the capacitor discharges rapidly via the crystal and transducer thus producing the required pulse for the transducer. The shock pulse produced in this way causes the transducer surface to hit the material surface and a damping oscillation will be observed at the resonance frequency of the crystal.

The receiver circuit does not need to much of modification but it is better to limit the input signal by using two diodes as in figure 25b. to clip the signal values above 0,7 Volts.

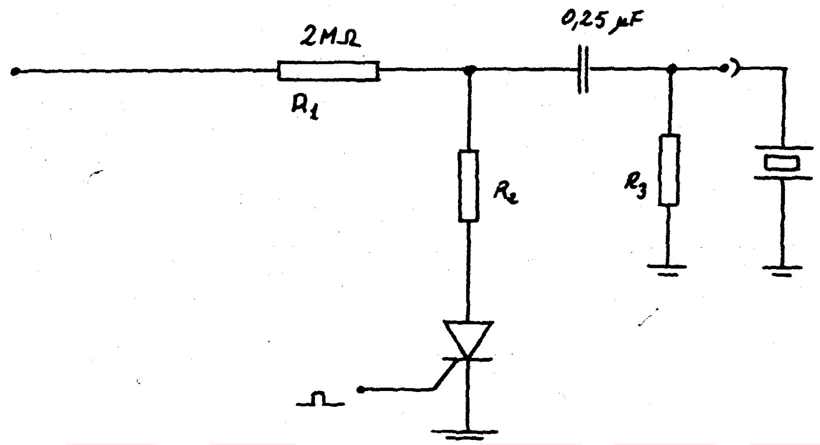


Figure 25.a. Transmitter circuit for pulse excitation.

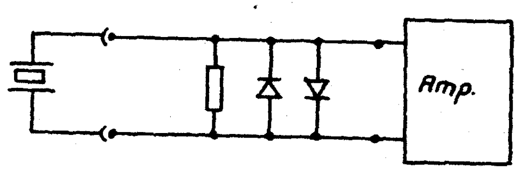


Figure 25.b. Receiver circuit modification.

CONCLUSION

In this study emphasis is given to testing of concrete, but, however, by using the same principles, it is possible to make reliable tests on other materials, solids, liquids and gases. Therefore it is better not to distinguish the testing of concrete from the general non-destructive testing of materials. Thus, Ultrasound offer a wide area of application in testing materials.

Although the destructive crushing tests give an exact result, the disadvantage of it is apparent. For tests where not very accurate or exact measurements are sufficient, as in the case of concrete, satisfactory results can be obtained by Ultrasonic methods. The advantage is being non-destructive, its simplicity and possibility of making tests on constructed elements.

Generally in non-destructive testing of materials two points are of importance: The operating frequency and the transducer. In fact one is the reason of the other. For different media and specimens the operating frequency and the transducer must be so selected that sensitivity and attenuation should be optimal.

Material limitations and particularly the lack of a powerful, good matching transducer has affected this study to a great extent. For this reason it was unfortunately not possible to have results by making tests on concrete. But principally, since the only difference is the medium, by simulating the effects in concrete satisfactory results have been obtained. The transit time in the medium can be measured with an error of less than 1%, the extension of transit time in the presence of an obstacle on the travel path, effects of temperature changes and echoes can be observed. This means that using the suitable transducer and frequency for the concerned medium , the instrument can easily be adapted for making measurements on other materials.

NOMENCLATURE

V	:	Velocity of sound
E	:	Elasticity Modulus
ρ	:	Density
PE	:	PiezoElectric
T	:	Transmitter
R	:	Receiver
V_L	:	Longitudinal Velocity
V_T	:	Transversal Velocity
μ	:	Poisson Ratio
λ	:	Wavelength
m	:	meter
s	:	Second
S	:	Length of the travel path
t	:	Time
h	:	Depth
Hz	:	Hertz
D	:	Diameter
W	:	Acoustic Impedance

APPENDIX .A

Sound velocity in gases:

$$V = \sqrt{k \cdot R \cdot T}$$

k = Specific heat. (for gases with two atoms like air, k=1,4.)

R = Gas constant. (R = 287 J/kg.K for air.)

T = Temperature in °Kelvin.

e.g. Sound velocity in air, at 20 °C,

$$V = \sqrt{1,4 \cdot 287 \cdot 293}$$

$$V = 343 \text{ m/s}$$

Calculation of crack depth

$$a^2 = h^2 + \left(\frac{s}{2}\right)^2$$

$$v = \frac{s}{t_1}$$

$$h = \sqrt{a^2 - \frac{s^2}{4}}$$

$$2a = v \cdot t_2 = s\,\frac{t_2}{t_1}$$

$$h = \sqrt{\left(\frac{t_2}{t_1}\right)^2 \cdot \frac{s^2}{4} - \frac{s^2}{4}}$$

$$h = \frac{s}{2}\sqrt{\left(\frac{t_2}{t_1}\right)^2 - 1}$$

APPENDIX B.

OPERATION MANUAL and CALIBRATION:

Mains connection : 220 V, 50 Hz. The instrument can be arranged for 110 V operation by changing the transformer connection inside.

The transmitting probe is connected to the right hand socket T, receiving probe is connected to the left hand socket R. Approximately one second after the instrument is switched on the transmitting probe generates Ultrasonic pulses and the receiving probe detects them after they have travelled through the specimen under test and the time elapsed occurs in µS on the display. This cycle is repeated every second.

In order to obtain good sound conductivity between the body under test and the probes a coupling medium such as grease, soft soap or rubber sheet must be used.

If S is the distance between two probes , t is the time read from the LED displays, the effective velocity ,

$$v = \frac{S}{t}$$

From the sound velocity thus determined conclusions may be drawn concerning the quality of the material under test, using the associated formula and tables in the text. If sound velocity in the sample is known then the thickness can be calculated by using the above formula, provided that the material is homogenous.

If the probes are located side by side then the thickness is,

$$d = \frac{v.t}{2}$$

and in the same manner large crack depths can be determined by,

$$h = \frac{v.t}{2}$$

Transmitter frequency can be adjusted by the potentiometers on the transmit circuit board to the frequency of the transducer.

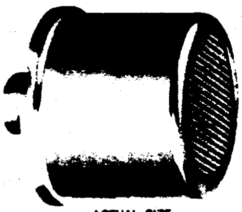
Receiver amplifier gain is adjusted by the potentiometer on the receiver circuit board.

The rate of the cycle pulses is adjusted by the potentiometer on the transmitter circuit board.(4,7 MΩ)

Calibration of the time measurement can be done by the potentiometer on the Control Unit board up to a delay of 100 µS.

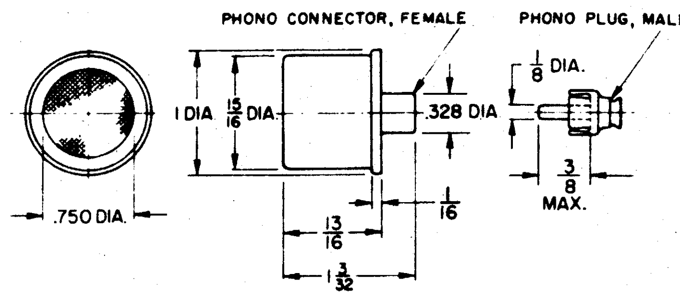
APPENDIX C

Characteristics of some of the components and transducers.



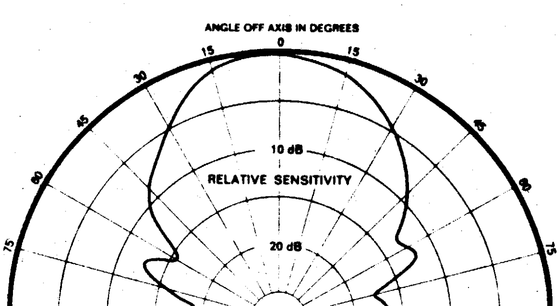
ACTUAL SIZE

Outline Dimensions

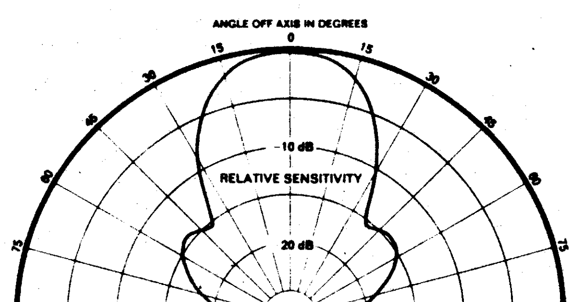


The MK-109 transducer is a transmitter-receiver that was developed for use with indoor intruder alarms and television remote control units. This transducer is recommended when high sensitivity is required in combination with very low power transistorized circuits. A phono connector termination is provided which permits quick transducer interchangeability if exact matching is necessary. A remarkably small change in resonant frequency with temperature change is exhibited by this model.

SPECIFICATIONS	TYPE 23	TYPE 42
AVAILABLE RESONANCE FREQUENCIES	23 kHz ± 2 kHz	37 kHz ± 2 kHz
FREQUENCY AT MAXIMUM IMPEDANCE (with no load) Specify Frequency Band Desired		42 kHz ± 2 kHz
BANDWIDTH (Untuned)	0.4 kHz	0.4 kHz
TRANSMITTING SENSITIVITY (10 mW available power) (minimum) (dB vs 1 microbar at 1 ft)	+20 dB	+25 dB
RECEIVING SENSITIVITY (Untuned with 2MΩ load) (dB vs 1 volt per microbar, minimum)	−50 dB	−50 dB
CAPACITANCE AT 1 kHz (nominal)	2800 pF ± 20%	1450 pF ± 20%
POWER RATING (Watts, cw, maximum)	.01 W	0.01 W
TEMPERATURE RATING (Maximum percentage change in resonance frequency over a temperature range from −30°F to 150°F)	1%	1%
WEIGHT	8 grams	8 grams
TUNING INDUCTANCE	15 mH	14 mH



DIRECTIONAL RADIATION PATTERN AT 23 kHz



DIRECTIONAL RADIATION PATTERN AT 42 kHz

Linden Sonotite® Standard Discs

THE BARIUM TITANATES

DIAMETER — ENGLISH/(METRIC)

	.250" (6.35mm)	.500" (12.7mm)	.750" (19.1mm)	1.000" (25.4mm)	1.125" (28.6mm)	1.5000" (38.1mm)	2.000" (50.8mm)
.007" 18mm) 15mHz	4-007-X $10.00	8-007-X $10.00	12-007-X $10.00	16-007-X $12.00	20-007-X $18.00	24-007-X $40.00	32-007-X $60.00
.010" 35mm) 10mHz	4-010-X $9.00	8-010-X $9.00	12-010-X $9.00	16-010-X $9.00	20-010-X $12.00	24-010-X $18.00	32-010-X $60.00
.020" 51mm) 5mHz	4-020-X $8.50	8-020-X $8.50	12-020-X $8.50	16-020-X $8.50	20-020-X $11.00	24-020-X $18.00	32-020-X $60.00
.040" 01mm) 2.5mHz	4-040-X $7.00	8-040-X $7.00	12-040-X $7.00	16-040-X $7.00	20-040-X $12.00	24-040-X $12.00	32-040-X $40.00
.050" 27mm) 2mHz	4-050-X $7.00	8-050-X $7.00	12-050-X $7.00	16-050-X $7.00	20-050-X $12.00	24-050-X $12.00	32-050-X $30.00
.100" .54mm) 1mHz	4-100-X $6.00	8-100-X $6.00	12-100-X $6.00	16-100-X $6.00	20-100-X $9.00	24-100-X $12.00	32-100-X $20.00
.200" .08mm) 500kHz	4-200-X $6.00	8-200-X $6.00	12-200-X $6.00	16-200-X $6.00	20-200-X $9.00	24-200-X $9.00	32-200-X $9.00
.500" 2.7mm) 200kHz	4-500-X $6.00	8-500-X $6.00	12-500-X $6.00	16-500-X $6.00	20-500-X $9.00	24-500-X $9.00	32-500-X $6.00

DIAMETER — METRIC/(ENGLISH)

	5mm (0.2")	10mm (0.4")	15mm (0.6")	20mm (0.8")	23mm (0.92")	30mm (1.2")	
.18mm (.007") 15mHz	3-018-X $10.00	7-018-X $10.00	9-018-X $10.00	13-018-X $10.00	15-018-X $12.00	21-018-X $18.00	
.25mm (.010") 10mHz	3-025-X $9.00	7-025-X $9.00	9-025-X $9.00	13-025-X $9.00	15-025-X $9.00	21-025-X 12.00	
.50mm (.020") 5mHz	3-050-X $8.50	7-050-X $8.50	9-050-X $8.50	13-050-X $8.50	15-050-X $8.50	21-050-X $11.00	
.64mm (.025") 4mHz	3-064-X $8.50	7-064-X $8.50	9-064-X $8.50	13-064-X $8.50	15-064-X $8.50	21-064-X $11.00	
.01mm (.040") 2.5mHz	3-101-X $7.00	7-101-X $7.00	9-101-X $7.00	13-101-X $7.00	15-101-X $7.00	21-101-X $12.00	
.13mm (.044") 25mHz	3-113-X $7.00	7-113-X $7.00	9-113-X $7.00	13-113-X $7.00	15-113-X $7.00	21-113-X $12.00	
.27mm (.050") 2mHz	3-127-X $7.00	7-127-X $7.00	9-127-X $7.00	13-127-X $7.00	15-127-X $7.00	21-127-X $12.00	
.54mm (.100") 1mHz	3-254-X $6.00	7-254-X $6.00	9-254-X $6.00	13-254-X $6.00	15-254-X $6.00	21-254-X $12.00	
.08mm (.200") 500kHz	3-508-X $6.00	7-508-X $6.00	9-508-X $6.00	13-508-X $6.00	15-508-X $6.00	21-508-X $9.00	
12.7mm (.500") 200kHz	3-1270-X $6.00	7-1270-X $6.00	9-1270-X $6.00	13-1270-X $6.00	15-1270-X $6.00	21-1270-X $9.00	

Customer's Guideline for Ordering Linden Sonotite Piezoceramic Discs

1. Use the Linden Sonotite standard disc diameter and frequency or thickness you wish to order.

2. The single unit price is included with each part number.

3. Substitute the exact Sonotite piezoceramic material you desire for the "X" found in each part number.

   Example: If you want a 1.0 inch diameter disc (code 16) with a thickness of .050 inch (code 050) fabricated from Sonotite 101 piezoceramic (code 101) the correct part number would be 16-050-101.

4. Standard Tolerances:

   Diameter ±0.005
   Thickness Parts up to 0.035, ±0.002
   Parts from 0.035 to 0.100, ±0.003
   Parts above 0.100, ±0.005

   Frequency ±5%

(Exact tolerance, conforming to your specifications, are available on diameters as well as frequency or thickness. Please contact Linden for a quotation to your specification.)

5. The Minimum Order for Linden Piezoceramic Products is $50.00.

(Mixed Part Numbers are accepted for Minimum Order Requirements but may not be used for following Discount Schedule.)

6. Discount Schedule for Quanity Disc Piezoceramic Purchases:

   1-9 Pieces multiply base disc by 1.00
   10-24 Pieces multiply base disc by .87
   25-49 Pieces multiply base disc by .75
   50-99 Pieces multiply base disc by .60

(Pricing for quantities greater than 99 are quoted on an individual basis.)

7. Delivery:

Standard discs of Sonotite piezoceramics are normally in stock. If stock is depleted delivery will range from 2 to 4 weeks.

8. Special Sizes and Frequencies:

Disc Diameters and/or Frequencies falling between those on the Standard Lists are quoted on an individual basis. Delivery of special disc diameters and frequencies are normally 4 weeks ARO.

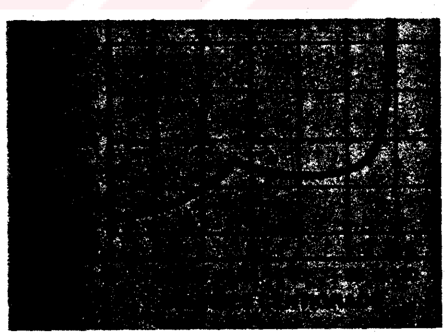
LINDEN LABORATORIES, INC
box 920, state college, pa. 16801 / 814 355-5491
A RESOURCE MANAGEMENT CORPORATION SUBSIDIARY

NOMINAL CHARACTERISTICS (twenty-four hours after polarization)

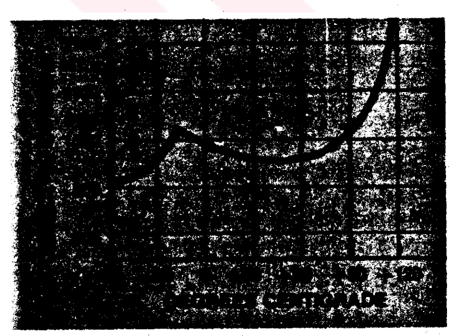
	501	502	601	602	603	701	702	801	802	803
PHYSICAL PROPERTIES										
DENSITY (g/cc)	5.6	5.6	5.5	5.5	5.6	5.6	5.6	5.3	5.3	5.3
YOUNG'S MODULUS ($x10^{10} NEW/m^2$)	10.4	10.2	11.5	10.0	11.6	11.0	10.0	11.2	12.0	11.2
CURIE TEMP. (°C)	120	120	120	120	120	133	133	145	145	145
MAX. OPERATING TEMP. (°C)	95	95	90	90	90	100	100	120	120	120
MECHANICAL Q	400	650	350	580	400	350	550	350	500	400
DIELECTRIC PROPERTIES										
DIELECTRIC CONSTANTS	1800	1800	1200	1200	1150	1400	1400	730	730	600
vs. 5 v/mil RMS	+30%	+8%	+35%	+8%	+30%	+35%	+12%	+20%	+6%	+17%
DISSIPATION FACTOR (%)	<0.9	<.06	<0.9	<0.7	<0.9	<0.9	<0.8	<0.7	<0.5	<0.7
vs. 5 v/mil RMS (%)	5.8	2.0	15.0	2.0	15.0	8.0	2.5	7.0	1.5	6.5
AGING (%/DECADE OF TIME)	-2.0	-2.0	-1.5	-1.8	-1.8	-1.5	-1.5	0.8	-1.0	-1.0
PIEZOELECTRIC PROPERTIES										
COUPLING COEFFICIENTS										
kr	0.35	0.34	0.32	0.32	0.32	0.32	0.32	0.28	0.28	0.28
k31	0.22	0.21	0.18	0.18	0.18	0.18	0.18	0.16	0.16	0.16
k33	0.50	0.48	0.48	0.50	0.48	0.50	0.52	0.44	0.50	0.50
AGING (%/DECADE OF TIME)	-2.0	-2.0	-2.0	-1.5	-2.0	-2.5	-2.0	-1.5	-1.8	-1.5
d_{31} ($x10^{-12}$ m/v)	-80	-78	-56	-60	-58	-60	-65	-40	-38	-36
g_{31} ($x10^{-3}$ v-m/NEW)	-4.6	-4.7	-5.1	-6.2	-5.9	-5.0	-5.8	-6.2	-5.9	-6.8
d_{33} (x10-12 m/v)	190	188	145	150	155	150	160	110	120	112
g_{33} ($x10^{-3}$ v-m/NEW)	12.0	11.9	13.2	15.9	14.9	12.8	14.5	17.0	18.6	21.2
FREQUENCY CONSTANTS (kc-INCHES)										
RADIAL	115	115	123	119	123	118	116	120	123	123
THICKNESS	97	97	102	100	102	101	100	98	100	100
BAR LENGTH	86	86	90	87	91	90	88	90	91	91
AGING (%/decade of time)	+0.5	+0.6	+0.3	+0.3	+0.3	+0.4	+0.5	-0.2	+0.4	+0.3

DIELECTRIC CONSTANT vs. TEMPERATURE

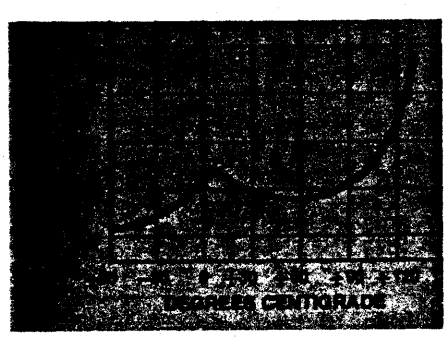
In certain applications the variation in temperature is a major concern for the design engineer. Since the piezoelectric ceramic is often utilized as a part of a total resonating circuit, the design engineer must be aware of the effect of temperature on the performance of the overall transducer.



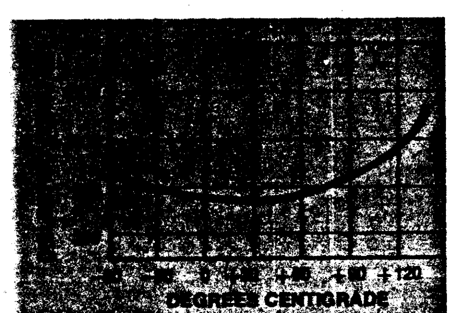
500 SERIES



600 SERIES



700 SERIES



800 SERIES

Linden Sonotite® Standard Discs

THE LEAD ZIRCONATE TITANATES

DIAMETER — ENGLISH/(METRIC)

	.250″ (6.35mm)	.500″ (12.7mm)	.750″ (19.1mm)	1.000″ (25.4mm)	1.125″ (28.6mm)	1.500″ (38.1mm)	2.000″ (50.8mm)
.007″ 18mm) 10mHz	4-007-X $14.00	8-007-X $14.00	12-007-X $14.50	16-007-X $15.00	Quoted on Request	Quoted on Request	Quoted on Request
.010″ 25mm) 8mHz	4-010-X $11.00	8-010-X $11.00	12-010-X $10.40	16-010-X $10.75	20-010-X $15.00	24-010-X $18.00	32-010-X $60.00
.015″ 38mm) 5mHz	4-015-X $10.00	8-015-X $9.00	12-015-X $10.40	16-015-X $10.75	20-015-X $15.00	24-015-X $18.00	32-015-X $60.00
.035″ 89mm) 25mHz	4-035-X $8.80	8-035-X $8.70	12-035-X $9.50	16-035-X $9.75	20-035-X $14.00	24-035-X 14.20	32-035-X $40.00
.080″ 03mm) 00mHz	4-080-X $8.60	8-080-X $8.50	12-080-X $9.40	16-080-X $9.50	20-080-X $13.00	24-080-X $13.80	32-080-X $30.00
.100″ 54mm) 300kHz	4-100-X $7.40	8-100-X $5.00	12-100-X $7.00	16-100-X $7.00	20-100-X $10.00	24-100-X $11.00	32-100-X $20.00
.125″ 18mm) 540kHz	4-125-X $7.40	8-125-X $6.00	12-125-X $7.00	16-125-X $7.00	20-125-X $10.00	24-125-X $11.00	32-125-X $20.00
.160″ 06mm) 500kHz	4-160-X $7.40	8-160-X $6.00	12-160-X $7.00	16-160-X $7.00	20-160-X $10.00	24-160-X $11.00	32-160-X $20.00
.250″ 35mm) 320kHz	4-250-X $8.00	8-250-X $6.00	12-250-X $8.00	16-250-X $8.00	20-250-X $12.00	24-250-X $14.00	32-250-X $16.00
.400″ .16mm) 200kHz	4-400-X $20.00	8-400-X $20.00	12-400-X $20.00	16-400-X $11.00	20-400-X $15.00	24-400-X $15.00	32-400-X $16.00

DIAMETER — METRIC/(ENGLISH)

	5mm (0.2″)	10mm (0.4″)	15mm (0.6″)	20mm (0.8″)	23mm (0.92″)	30mm (1.2″)	
.18mm (.007″) 10mHz	3-018-X $13.00	7-018-X $13.00	9-018-X $13.00	Quoted on Request	Quoted on Request	Quoted on Request	
0.38mm (.015″) 5mHz	3-038-X $13.00	7-038-X $13.00	9-038-X $13.00	13-038-X $13.00	15-038-X $13.00	21-038-X $18.00	
0.50mm (.020″) 4mHz	3-050-X $11.00	7-050-X $11.00	9-050-X $11.00	13-050-X $11.00	15-050-X $11.00	21-050-X $15.00	
0.83mm (0.32″) 2.5mHz	3-083-X $11.00	7-083-X $11.00	9-083-X $11.00	13-083-X $11.00	15-083-X $11.00	21-083-X $15.00	
0.90mm (.035″) .25mHz	3-090-X $11.00	7-090-X $11.00	9-090-X $11.00	13-090-X $11.00	15-090-X $11.00	21-090-X $15.00	
1.02mm (.040″) 2mHz	3-102-X $11.00	7-102-X $11.00	9-102-X $11.00	13-102-X $11.00	15-102-X $11.00	21-102-X $15.00	
1.63mm (.064″) .25mHz	3-163-X $10.00	7-163-X $10.00	9-163-X $10.00	13-163-X $10.00	15-163-X $10.00	21-163-X $14.00	
2.54mm (.100″) 1mHz	3-254-X $10.00	7-254-X $10.00	9-254-X $10.00	13-254-X $10.00	15-254-X $10.00	21-254-X $14.00	
4.06mm (.160″) 500kHz	3-406-X $8.00	7-406-X $8.00	9-406-X $8.00	13-406-X $8.00	15-406-X $8.00	21-406-X $8.00	

Customer's Guideline for Ordering Linden Sonotite Piezoceramic Discs

1. Use the Linden Sonotite standard disc diameter and frequency or thickness you wish to order.

2. The single unit price is included with each part number.

3. Substitute the exact Sonotite piezoceramic material you desire for the "X" found in each part number.

   Example: If you want a 1.0 inch diameter disc (code 16) with a thickness of .050 inch (code 050) fabricated from Sonotite 101 piezoceramic (code 101) the correct part number would be 16-050-101.

4. Standard Tolerances:

   Diameter ±0.005
   Thickness Parts up to 0.035, ±0.002
   Parts from 0.035 to 0.100, ±0.003
   Parts above 0.100, ±0.005

   Frequency ±5%

(Exact tolerance, conforming to your specifications, are available on diameters as well as frequency or thickness. Please contact Linden for a quotation to your specification.)

5. The Minimum Order for Linden Piezoceramic Products is $50.00.

(Mixed Part Numbers are accepted for Minimum Order Requirements but may not be used for following Discount Schedule.)

6. Discount Schedule for Quanity Disc Piezoceramic Purchases:

   1-9 Pieces multiply base disc by 1.00
   10-24 Pieces multiply base disc by .87
   25-49 Pieces multiply base disc by .75
   50-99 Pieces multiply base disc by .60

(Pricing for quantities greater than 99 are quoted on an individual basis.)

7. Delivery:

Standard discs of Sonotite piezoceramics are normally in stock. If stock is depleted delivery will range from 2 to 4 weeks.

8. Special Sizes and Frequencies:

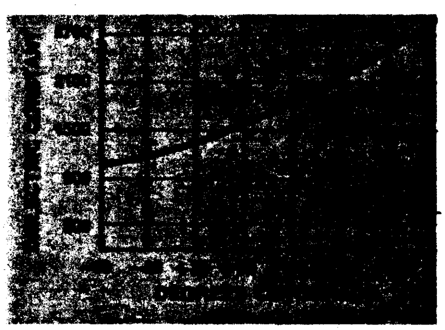
Disc Diameters and/or Frequencies falling between those on the Standard Lists are quoted on an individual basis. Delivery of special disc diameters and frequencies are normally 4 weeks ARO.

LINDEN LABORATORIES, INC
box 920, state college, pa. 16801 / 814 355-5491
A RESOURCE MANAGEMENT CORPORATION SUBSIDIARY

NOMINAL CHARACTERISTICS (twenty-four hours after polarization)

	101	102	103	104	105	106
PHYSICAL PROPERTIES						
DENSITY (g/cc)	7.6	7.5	7.7	7.4	7.5	7.5
YOUNG'S MODULUS (x10^{10} NEW/m^2)	7.1	7.6	7.2	9.0	6.1	6.0
CURIE TEMP (°C)	350	310	320	340	200	200
MAX. OPERATING TEMP. (°C)	150	150	150	150	120	120
MECHANICAL Q	80	230	900	1400	75	75
DIELECTRIC PROPERTIES						
DIELECTRIC CONSTANTS	1700	1200	1000	400	2700	3200
vs. 5 v/mil RMS	+30%	+10%	+10%	+25%	+30%	+30%
DISSIPATION FACTOR (%)	1.5	0.5	0.5	0.5	2.5	2.5
vs. 5 v/mil RMS(%)	10.0	2.5	2.5	7.0	12.0	12.0
AGING (%/DECADE OF TIME)	-0.5	-3.0	-3.0	-2.0	-0.7	-0.5
PIEZOELECTRIC PROPERTIES						
COUPLING COEFFICIENTS						
kr	0.55	0.51	0.50	0.25	0.58	0.65
k 31	0.32	0.31	0.30	0.14	0.36	0.39
k33	0.69	0.67	0.65	0.31	0.70	0.77
AGING (%/DECADE OF TIME)	-1.0	-2.0	-2.0	-1.5	-1.0	-1.0
d_{31} (x10^{-12} m/v)	-150	-112	-100	-27	-230	-270
g_{31} (x10^{-3} v-m/NEW)	-10.8	-10.6	-10.1	-7.6	-9.0	-9.0
d_{33}(x10^{-12} m/v)	340	260	220	70	475	550
g_{33} (x10^{-3} v-m/NEW)	23.0	25.0	25.0	20.0	20.5	19.5
FREQUENCY CONSTANTS (kc-INCHES)						
RADIAL	81	85	89	104	83	78
THICKNESS	78	80	77	90	72	69
BAR LENGTH	60	63	63	75	60	59
AGING (%/DECADE OF TIME)	+0.1	+0.8	+0.8	+0.5	+0.2	+0.1

DIELECTRIC CONSTANT vs. TEMPERATURE



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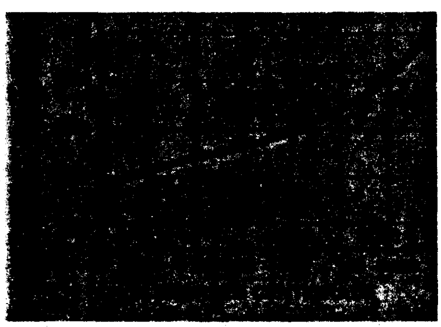

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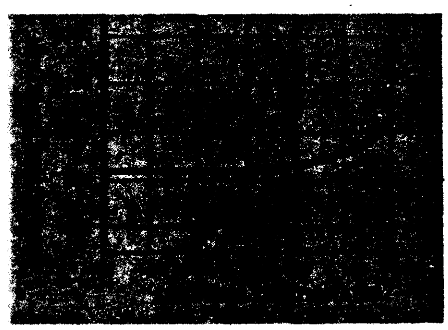

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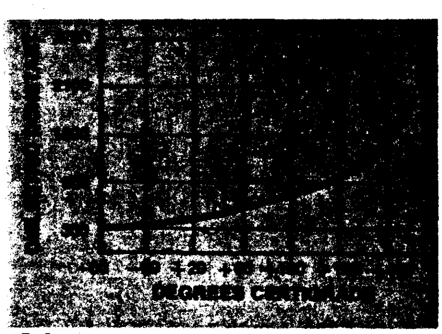

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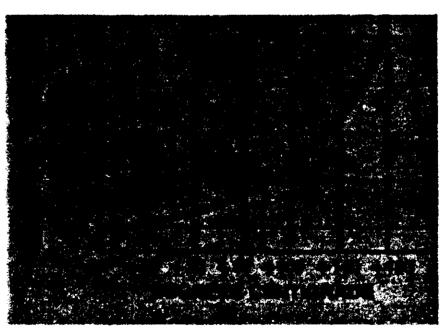

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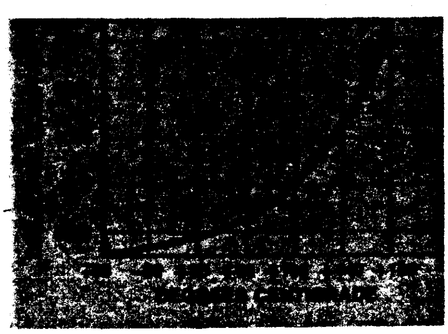


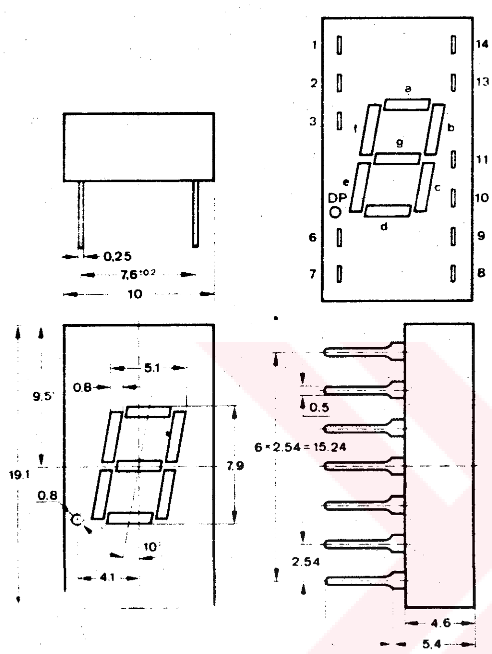
106

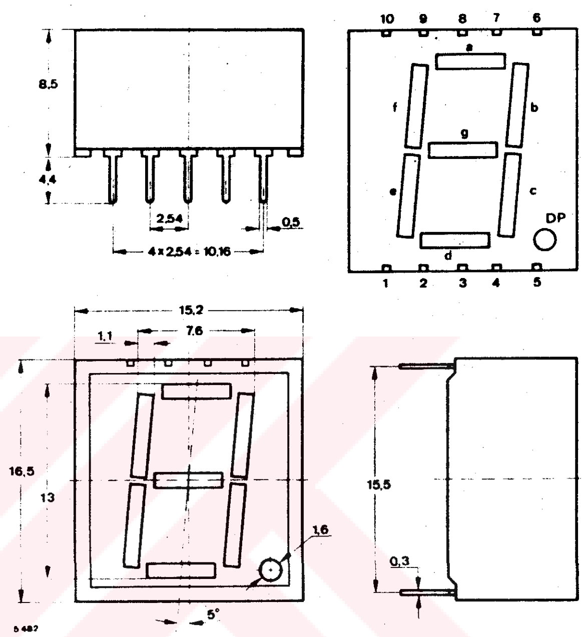
ptoelectronic devices

ght emitting diode displays

ype	Category	character height	Fig. Nr.	I_V and	U_F	Luminous paint	Spectral curve
				at I_F = 20 mA			
		mm		mcd	V		
QY 71	7 segments	8	7	0,4	1,6	red	4
QY 91 A QY 91 K	7 segments	13	8	0,6	1,6	red	4
QY 92 A QY 92 K	7 segments	13	8	0,8	2,7	green	7
QY 93 A QY 93 K	7 segments	13	8	0,8	2,7	yellow	8

ıta book reference: B 2 A





n-Connections:

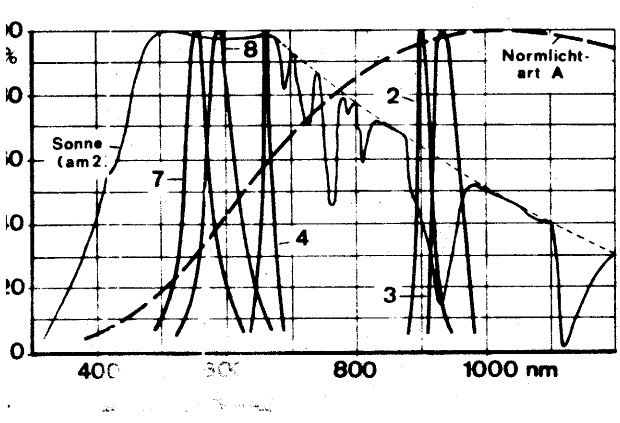
1 Cathode a
2 Cathode f
3 Common anode
6 Cathode DP
7 Cathode e
8 Cathode d
9 Common anode
10 Cathode c
11 Cathode g
13 Cathode b
14 Common anode

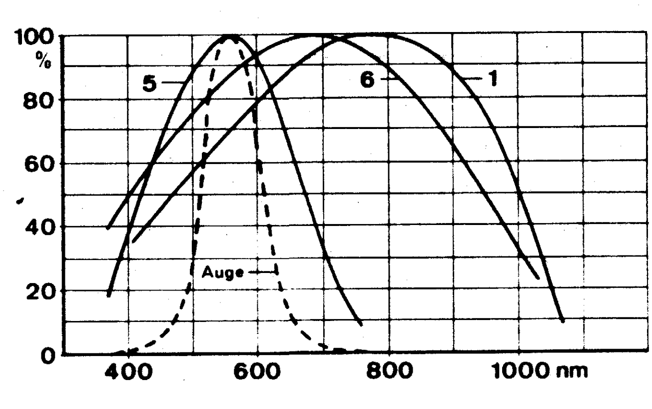
g. 5: ≈ 20 A 14 DIN 41 866
≈ JEDEC MO 001 AA

Pin connections:

Pin	CQY 91 A CQY 92 A CQY 93 A	CQY 91 K CQY 92 K CQY 93 K
1	Segment e	Segment e
2	Segment d	Segment d
3	Anode	Cathode
4	Segment c	Segment c
5	DP	DP
6	Segment b	Segment b
7	Segment a	Segment a
8	Anode	Cathode
9	Segment f	Segment f
10	Segment g	Segment g

Fig. 6: Special case





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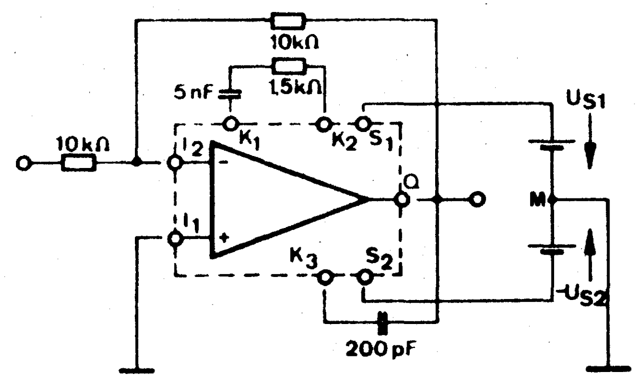
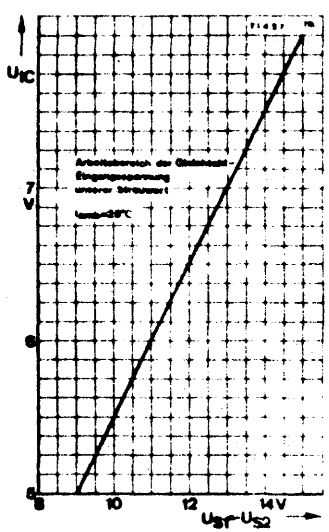
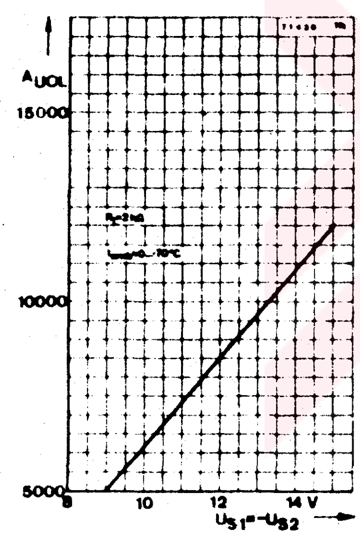
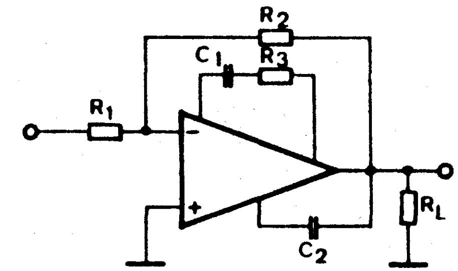


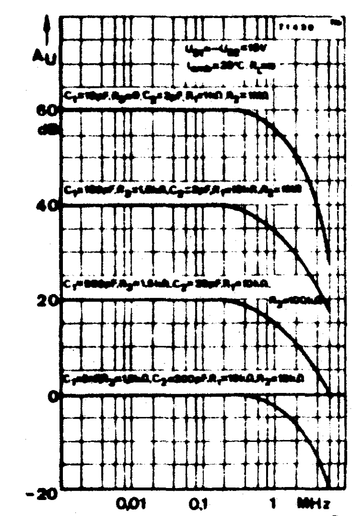






A	dB	C_1	R_3	C_2
1	0	5n	1K5	200P
10	20	500P	1K5	20P
100	40	100P	1K0	3P
1000	60	10P	0	3P

Frequency compensating components



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