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TRANSIT TIMES OF COMPRESSION SOUND WAVES
THROUGH ALUMINUM PLATE

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ABSTRACT

Experiments are described which show that the velocity of compressional waves along a thin plate varies as a function of the frequency of the waves. In terms of transit times in aluminum the value is between 4.02 and 4.94 microseconds per inch.

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INTRODUCTION

Mechanical energy may be transmitted through a solid in several ways. In the case of compressional, or dilatational waves in which the particle motion is in the direction of propagation, the velocity of propagation is determined by the boundary conditions. There are two special limiting conditions, one in which the cross section is infinite and one in which the cross section is very small. The velocity in the former case is higher than in the latter. For intermediate conditions where the cross sectional dimensions are comparable to the wave length of the elastic waves, the velocity should fall between that of the two limiting cases. This paper describes an experiment designed to show that this will be true for conditions of interest in our work here.

TRANSIT TIMES OF COMPRESSION SOUND WAVES THROUGH ALUMINUM PLATE

Theory

When a plate is struck at one end, several waves are propagated down its length. If a strain sensitive voltage generator is mounted on the plate, it will start to generate a voltage when the first wave front reaches its position. By mounting two of these pick-ups a known distance from each other on the plate, the transit time can be found by observing the total time required for the wave to reach each pick-up and then taking the difference of these two time values.

The work reported in this memo is concerned only with the compressional or dilatational wave in which particle motion is parallel to the direction of propagation. It is this wave which travels at the highest velocity in aluminum.

In the derivation of the velocity of sound by compressional waves, in a solid two limiting conditions are normally considered. One case is that of propagation along a wire when the wave length of the sound wave is long compared with the diameter of the wire. The velocity of propagation of compressional wave for this case is determined by Young's modulus and the density of the material. In the second limiting case, the medium is considered "infinite" in extent, that is the dimensions are large compared with the wave length of the sound waves. The velocity of propagation here is determined by the bulk modulus and the density of the material.

From a physical viewpoint the difference between the two derivations may be explained as follows. In the case of the wire, compression of an element of length of the wire will be accompanied by a lateral expansion. This effectively lowers elastic rigidity to compression as compared to the "infinite" medium where a compression along the direction of propagation cannot be accompanied by a transverse expansion.

The case of propagation of a compression wave along a plate is more complicated. However, one should expect that the behavior here would fall between the two limiting cases described above. In particular, for a given plate thickness, the velocity of propagation should be expected to approach that of an infinite solid as the wave length of the wave motion becomes small compared to the thinner dimension of the plate.

When a plate is struck by a moving object a wave will be set up which may be considered as a summation of a large number of sinusoidal waves of various frequencies. The greater the velocity of impact, the higher the frequencies which are generated in the composite wave. Therefore, the hypothesis that velocity varies with frequency may be checked by measuring the velocity of transmission for different impact conditions.

Apparatus

Two skin type crystals were mounted at the one foot and three foot points on the center line of a one foot by four foot aluminum plate. The skin type pick-ups are sensitive to compression along the length of the plate. The output of each crystal was recorded on an oscilloscope. Both oscilloscopes were connected to a common trigger voltage. Polaroid Land Cameras were used to record the traces from each oscilloscope. By measuring the time from the beginning of each sweep to the beginning of crystal output and then taking the difference, the transit time of the wave was found over the two foot interval.

Side BB shots made slightly above crystal No. 3

For the above method to be valid, both oscilloscopes must be triggered simultaneously. In order to check this condition the output of one crystal was made common to both oscilloscopes. Times to the beginning of voltage output on each oscilloscope were found to be equal. Therefore, they were being triggered simultaneously.

Triggering voltage was obtained from the voltage drop produced across a resistor when a small thyatron was fired. To obtain different impact conditions a pendulum, hammer, and a BB gun were used to strike the plate. In the case of the pendulum and hammer, the thyatron fired when contact was made with the plate. For the BB shots a third crystal was mounted near the leading edge of the plate. Output of this crystal then fired the thyatron triggering the oscilloscopes.

The time base of the oscilloscope was calibrated immediately before or after each shot by means of a sine wave generator which in turn had been checked against a 1000 cycle tuning fork.

⁺ Memo: G. E. Hansche from R. S. Claassen, Ref. Sym: 1123-(8), January 28, 1952.

Procedure

Transit time, using the pendulum, was first found in plates of four thicknesses, .032", .064", .081", and .125". No significant differences were observed due to plate thickness, therefore, the .081" plate only was used for the remainder of the test. The average transit time of eight blows on the four plates was 4.9 microseconds per inch.

By striking the .081" plate with a hammer, a slightly lower transit time of 4.8 microseconds per inch was obtained as an average of four blows. No consistent change in transit times occurred when the intensity of the blow was changed.

Two types of shots were made with the BB gun. In the first type the BB struck the thin edge of the plate travelling in the same direction as the compression wave which was set up by the impact. The rise time of the compression wave is a function of the time required to stop the BB when it impacts the plate. In the second type of shot the BB struck the flat side of the plate. Immediately after impact a compression wave travels ahead of the BB across the thickness of the plate. This compression is accompanied by a lateral expansion which in turn generates a compression wave travelling along the long dimensions of the plate. This initial compression wave has a very fast rise time since its duration is controlled by the time it takes for a compression wave to travel across the thickness of the plate.

The average transit time for both the edge and the side BB shots was 4.6 microseconds per inch. A comparison was made in these two cases of the time for the voltage to rise from 10 per cent to 90 per cent of its maximum value. Side shots gave the more rapid rise time. In both the edge and side shots the first crystal had a shorter rise time. This is to be expected since the variation of velocity with frequency would cause dispersion and the initial pulse will be "smeared" out as it travels away from the origin.

Results are tabulated below.

Transit Times

Pendulum - Average of eight blows

Plates .031", .094", .081" and .125"

Average Transit Time = 4.9 microsecond per inch

Hammer - Four Blows on .081 plate

Average Transit Time = 4.8 microsecond per inch

BB Gun - Five edge shots .081" plate

Average Transit Time = 4.6 microsecond per inch

BB Gun - Four side shots .081" plate

Average Transit Time = 4.6 microsecond per inch

Rise Times

BB Gun - Four Shots .081" plate

Average Rise Time

Edge Shots

Crystal No. 1 3.2 microsecond

No. 2 3.6 microsecond

Side Shots

Crystal No. 1 1.9 microsecond

No. 2 2.0 microsecond

The accompanying figure shows sample traces of the crystal output for the four types of impacts. The voltage scales are different for each picture.

Conclusions

Transit times in aluminum were calculated from data given by Mason⁺ to be 4.94 microsecond per inch in wire and 4.02 microsecond per inch for the longitudinal wave in an infinite solid. For comparison transit time for the shear wave in solid is 8.09 microsecond per inch.

Due to the higher velocity and smaller mass the shortest wave-lengths were set up by the BB shots. Mason's results say that as the wave-length becomes shorter, a given cross section begins to act as an infinite solid for which the transit time is 4.02 microsecond per inch. The experimental data reported here indicate that such an effect can be observed in plates. Since neither a very small cross section nor an infinite solid was actually used, the results should fall, as they do, between Mason's two extremes.

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⁺ Mason, W. P., "Piezoelectric Crystals and Their Application to Ultrasonics", D. Van Nostrand Company, Inc., 1950, Pages 391 and 413.

Output of Second Pickup from
Hammer Blow
50 KC Sine Wave

Output of Second Pickup from
Pendulum Blow
50 KC Sine Wave

Output of First Pickup from
Edge BB Blow
200 KC Sine Wave

Output of First Pickup from
Side BB Blow
50 KC Sine Wave

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