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GENERATION OF MECHANICAL VIBRATIONS BY PENETRATING PARTICLES*

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Mechanical oscillations of lead-zirconate-titanate piezoelectric disks have been observed when penetrating high-energy (1.0-BeV) beams of electrons impinge on the disks. Radial and compressional modes of vibration have been observed in the frequency range 40-158 kHz. Possible applications of this observation to particle detection at very high energies are discussed. The observed phenomenon also has a possible connection with measurements of gravitational waves.

Recently a suggestion was made[1] that the very great energies carried by high-energy particles might permit particle detection by macroscopic means not hitherto considered. Examples are (a) sound vibrations of crystals or solids and (b) emission of infrared radiation. A third possibility is (c) the modification of strain in a transparent body by the sudden deposition of the energy of an energetic penetrating particle in that medium. Such strain changes could be observed with polarized light at a condition of maximum extinction. Other optical and mechanical possibilities exist.

We have recently observed mechanical, or sound, vibrations in ceramic piezoelectric disks of lead-zirconate-titanate (PZT) struck by high-energy electrons. Four $\frac{1}{2}$-in.-thick disks of PZT[2] were placed in the geometrical configuration shown in Fig. 1. The PZT disks were polarized and connected together electrically as shown in the figure. Each disk was acoustically insulated from its surroundings by a rubber-band suspension. The combination was mounted in a small aluminum box which was placed in vacuum in the target chamber of the electron scattering apparatus of the Stanford MARK III accelerator. Free oscillations of the disks were produced by the impinging beam. Although we have employed electrons in our tests we expect that all energetic particles will produce mechanical vibrations.

A wide-band, low-impedence, common-base-configuration amplifier was used to examine the induced vibrations. Since the most prominent resonant frequencies of the disks were near 40 (radial mode) and 158 kHz (compressional mode), most of the studies were concentrated on these modes. Electrons of energy 1.00 and 0.20 BeV were used in pulses, each lasting about 1.0 μsec and containing 10^4-10^6 electrons. The cross section of the incident 1.00-BeV beam was about 3

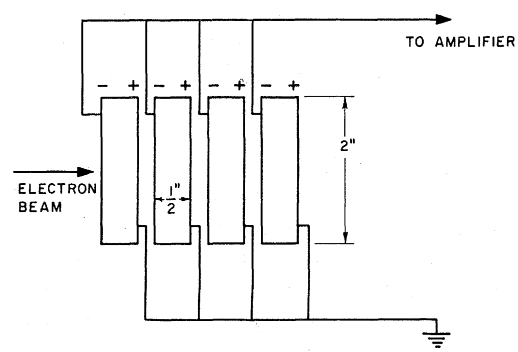


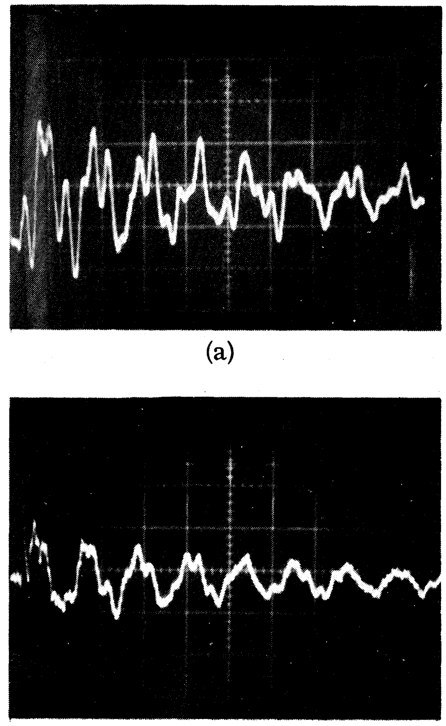
FIG. 1. Schematic diagram of the PZT disk assembly exposed to a high-energy electron beam.

mm×3 mm. The electromagnetic showers generated by these particles extend through all the disks and a very rough estimate indicates that about 30% of the energy of each particle is deposited, on the average, in the PZT disks. Signals corresponding to bursts of 4×10^6 electrons/pulse (1.0-BeV particles) were observed to be about 125 μV peak to peak in magnitude at the 15-Ω input of the amplifier. The exact value of the signal depends on the mode excited. In general, both modes were excited as shown in the oscilloscope photographs of Fig. 2. The relative signal sizes of the radial and compressional modes could be varied by aligning the disks as indicated in Fig. 1 and by rotating them through 90°. In the latter case the radial mode was emphasized. A rough calculation of the energy conversion efficiency indicates that the mechanical energy in the compressional mode is approximately 2×10^{-10} of the deposited beam energy.

The deposition of a pulse of 0.2-BeV electrons was more effective in producing vibrations than a pulse of the 1.0-BeV electrons. This may be a result of greater capture of shower energy and larger diameter of the input beam at lower energies. This effect is now under study.

It is possible that the beam of electrons produces an instantaneous hot zone in the interior of the disk, from which a shock wave passes out to the periphery, thus producing the observed oscillations. It is possible also that more direct conversion of the incident energy into electrical signals may take place.[3,4] Surface heating of crystals by light, microwaves, and low-energy electrons has been observed and also leads to mechanical vibrations.[5]

Besides the intrinsic physical interest involved in a further study of the particle-induced mechanical vibrations, we are interested in increasing the sensitivity of the amplifier and associated equipment to see how close we can come to detecting individual high-energy particles by their induced vibrations. Reducing the amplifier noise is the most obvious way of obtaining a rather large improvement in this direction. Low temperature of the input resistance will reduce electrical noise and decreasing the receiver band width will also be advantageous. We do not know whether clamping the disks to bring out a specific mode will help, nor whether low temperature of the piezoelectric material is desirable. Making the samples thinner will increase the probability of observing ultrasonic frequencies greater than 1.0 MHz.



(a)

(b)

FIG. 2. Oscilloscope photograph of the radial (40-kHz) and compressional (158-kHz) modes of mechanical vibrations induced by a pulse of 1.0-BeV electrons. Case (a) Beam parallel to axis of disks. Case (b) Beam perpendicular to axis of disks. In each case the horizontal scale corresponds to 20 μsec/div.

If the sensitivity can be increased there is an obvious application of these techniques to total-absorption nuclear-cascade and total-absorption shower-cascade counters.[1] Besides the present direct use of piezoelectric absorber, one could possibly employ, e.g., a block or series of disks of high-density tungsten as absorber of the high-energy radiation and strap a piezoelectric transducer to the block or to each disk to bring out an electrical signal to a resonant circuit. Indeed, it seems possible that a very large cosmic-ray event could excite mechanical vibrations in a metallic cylinder at its resonant frequencies and thus could provide an accidental background for experiments on "gravitational waves."

Our present experiments suggest additional studies of particle-induced excitation of mechanical vibrations in single crystals and liquids. In particular, an investigation of liquid helium, above and below the lambda point, would seem to be of some interest.

In principle, the efficiency could be considerably improved by chopping the high-energy particles at a rate corresponding to the resonant frequency of the piezoelectric detector. It may be noted, however, that in many applications the particle beams are not chopped.

We wish to thank Dr. Vincent Salmon of the Stanford Research Institute and Dr. E. B. Hughes of the High Energy Physics Laboratory for important help and advice in planning these experiments. We also wish to thank Dr. Robert Callahan of Channel Industries, Mr. Larry Buss of the High Energy Physics Laboratory, Professor Felix Bloch of Stanford University, Dr. Richard Cook of Environmental Science Services Administration, and Dr. G. Van Hoven of the University of California at Irvine for their help and stimulation.

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BACKWARD ELASTIC π^+p SCATTERING FROM 2.18 to 5.0 BeV/c*

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Differential cross sections for π^+p elastic scattering in the angular region $-0.6 \gtrsim \cos\theta_{\text{c.m.}} \gtrsim -0.98$ are presented for 13 incident pion momenta from 2.18 to 5.0 BeV/c. The striking features of the data are a backward peak at all momenta and a dip in the cross section at $u \approx -0.17$ for momenta between 2.75 and 5.0 BeV/c.

This Letter reports the results of an optical spark-chamber experiment performed at the Argonne National Laboratory zero-gradient sychrotron to measure the backward angular distribution of the cross section for π^+p elastic scattering. These cross sections, for 13 momenta from 2.18 to 5.0 BeV/c, result from 15 300 events recovered from 211 000 photographs. Pions scattered at laboratory angles between 70° and 150°, corresponding to $-0.6 \gtrsim \cos\theta_{\text{c.m.}} \gtrsim -0.98$, were studied. Thus our data cover $-0.7 \leq u \leq 0.1$ at 2.18 BeV/c and $-1.1 \leq u \leq 0$ at 5.0 BeV/c.[1]

The experimental layout is shown in Fig. 1. The external proton septum beam, with a momentum resolution of 1% full width at half-maximum and a central momentum uncertainty of less than 1%, struck a 12-in.-long liquid-hydrogen target. A gas threshold Čerenkov counter CG, not shown in Fig. 1, was used to separate pions from protons and kaons in the beam. At 2.18 BeV/c the beam intensity was 30 000 particles (15 000 pions) per burst, while at 5.0 BeV/c the intensity was 150 000 particles (40 000 pions) per burst.

A trigger of the system occurred when signals were detected from the beam counters (CG, B1, and B2), one of the proton counters (P1 or P2 in Fig. 1), and one of the six pion counters ($\pi1$-$\pi6$ in Fig. 1). A signal from the water Čerenkov counter was also required when either counter $\pi1$ or $\pi2$ detected a particle; this eliminated trig-

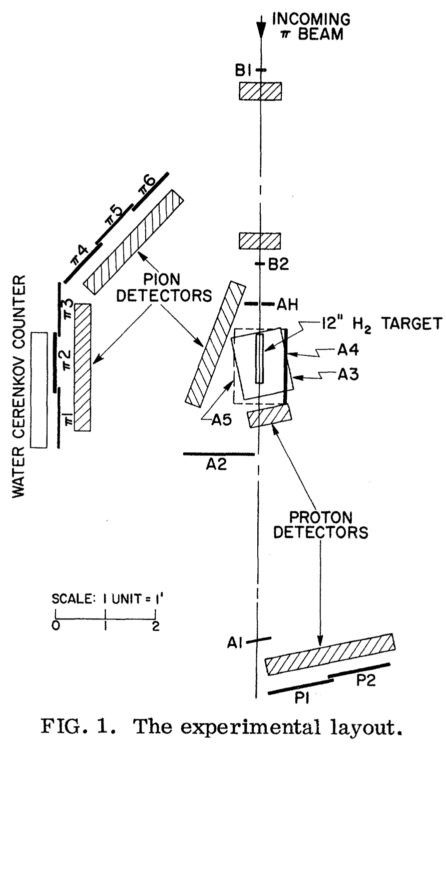
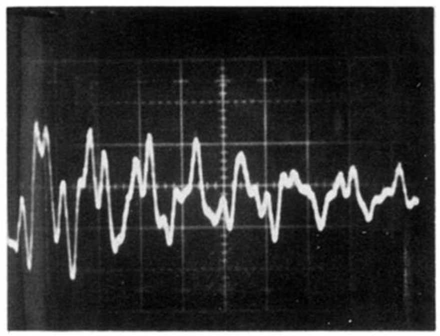
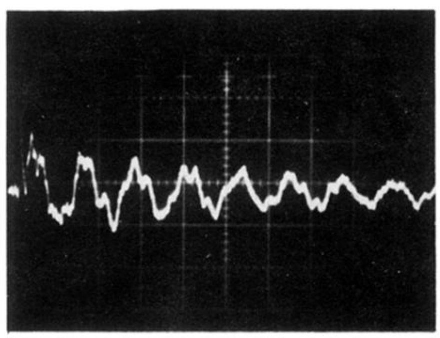


FIG. 1. The experimental layout.



(a)



(b)

FIG. 2. Oscilloscope photograph of the radial (40-kHz) and compressional (158-kHz) modes of mechanical vibrations induced by a pulse of 1.0-BeV electrons. Case (a) Beam parallel to axis of disks. Case (b) Beam perpendicular to axis of disks. In each case the horizontal scale corresponds to 20 μsec/div.