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TECHNICAL REPORT

RESPONSE OF MICROPHONE METEORITE DETECTORS TO THE IMPACT OF HIGH VELOCITY PARTICLES

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RESPONSE OF MICROPHONE METEORITE DETECTORS TO THE IMPACT OF HIGH VELOCITY PARTICLES*

I. INTRODUCTION

Most of the direct measurements on the properties of micrometeoroids have utilized microphone detectors. These consist of piezoelectric crystals which are mechanically coupled to metallic plates or "sounding boards". The crystal responds to mechanical vibrations induced in the sounding board by the impact of a micrometeorite. The output of the microphone is an electrical signal with an amplitude proportional to the magnitude of the mechanical vibrations. Despite the widespread use of this type of sensor, the overall response of the detector to dynamic properties of the meteoroids has not been firmly established. In their comprehensive compilation of meteorite data, Alexander, et al[1] assumed a momentum dependence based on the results of tests conducted at very low impact velocities. A momentum dependence has also been reported[2] for impact velocities up to about 4 km/sec. In contrast, the theoretical treatment of Stanyukovich[3] and the experiments of Denardo[4] using large particles at velocities up to 7.8 km/sec suggest an energy dependence.

This report gives the results of tests using very small particles with impact velocities up to 7.5 km/sec. Although the results are not completely definitive, they show that the overall response of a microphone detector lies somewhere between the momentum and energy dependences suggested by other experimenters.

II. EXPERIMENTAL APPARATUS AND PROCEDURES

High speed particles from the STL electrostatic accelerator[5] were used for the measurements described in this report. In this device, small particles are charged electrically by an inductive process[6] and are injected into the accelerating field of a 2-million volt Van de Graaff generator. The final velocity attained

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by the particle is given by

$$v = (2\ qV_a/m)^{1/2} \tag{1}$$

where V_a is the accelerating voltage and m and q are the particle mass and charge. As shown in Ref. 6, the q/m of the particles is proportional to the reciprocal of particle radius. Consequently, the electrostatic method of accelerating particles is applicable only to small particles. Under optimum conditions, a 1 micron diameter iron particle achieves a final velocity of about 7 km/sec. Higher velocities can be achieved with smaller particles, but the momentum of smaller particles is reduced correspondingly. The limiting sensitivity of the microphone detectors prohibited the use of higher velocity particles for these experiments.

The charge and velocity of each particle from the accelerator are determined prior to impact by measuring the magnitude and duration, respectively, of a voltage signal induced on a cylindrical drift tube of known capacitance and length which the particle traverses axially. The charge is given by $q = CV_i$ where V_i is the magnitude of the induced voltage pulse and C is the capacitance of the drift tube. The velocity is simply $v = \ell/t$ where t is the time required to pass through a cylinder of length ℓ. Knowing the accelerating voltage, the mass of the particle can be computed from Eq. (1).

The signal on the drift tube was amplified and displayed on one trace of a dual beam oscilloscope while the signal from the microphone detector was displayed on the other. Both traces were triggered by the leading edge of the voltage pulse from the velocity-charge detector. By taking account of the flight time from the charge detector to the point of impact, one can be assured that both signals were produced by the same particle.

The crystal transducer acquired for these tests was typical of those used in flight experiments. It consisted of a cylindrically shaped lead zirconate crystal encapsulated in an aluminum can. Preliminary tests showed that the microphone was not sufficiently sensitive to be used directly with particles from the accelerator. As a consequence of this, the crystal was removed from the can and suspended in a rubber grommet with its axis parallel to the beam of particles from the accelerator. The signal from the crystal was derived from a pickup loop at one end of the crystal. The face of the crystal exposed to the beam of particles was grounded. Two types of impact surfaces were used. The first was a layer of conducting silver paint while the other was a polished aluminum disc cemented to the crystal. Since there was no apparent difference in response for the different surfaces, the results from both were combined in the data analysis.

The signal from the microphone was fed to a wide band amplifier. The waveform at the output of the amplifier was an exponentially decreasing oscillatory signal with frequency of about 100 kc as illustrated in Fig. 1-a. The signal shown resulted from the impact of a glass bead dropped from a height of a few centimeters. To reduce some of the low frequency noise problems associated with mounting the microphone in the test chamber, the amplified signal was fed through a relatively low Q resonant circuit tuned to the resonant frequency of the crystal. The circuit is shown in Fig. 1-b and a typical signal is illustrated in Fig. 1-c. The amplitude of the microphone signal was measured at the point of maximum excursion from the base line. Since the circuitry is composed entirely of linear elements and the frequencies are fixed, it can be shown that the measured maximum amplitude is always proportional to the amplitude of the first half cycle at the output of the crystal.

III. RESULTS

Most of the hypotheses regarding the response of microphone detectors can be reduced to the form $V = K\ mv^{\alpha}$ where the value of K depends upon the nature of the impact, m and v are

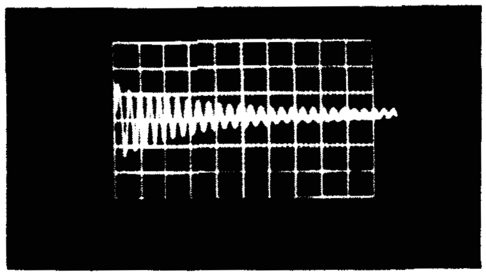

Figure 1-a

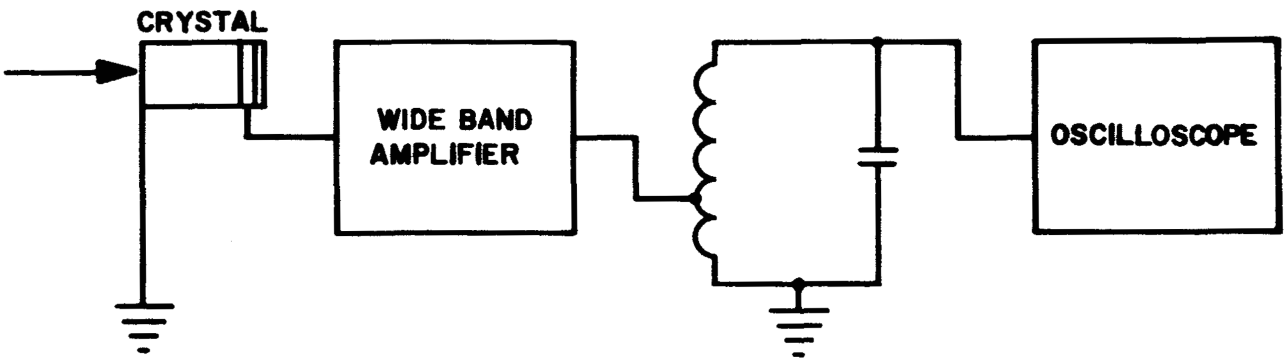

Figure 1-b

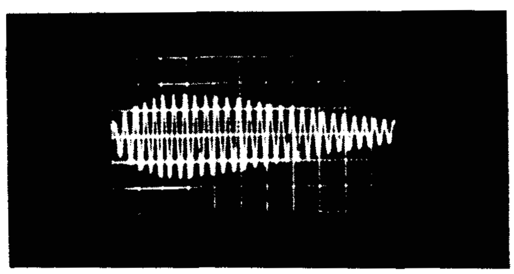

Figure 1-c

Figure 1. Schematic Diagram of the circuit used in the Microphone Detector Tests. The waveform at the top of the figure is obtained at the output of the amplifier while the waveform at the bottom is at the output terminal of the tuned circuit.

the particle mass and velocity, and α is an undetermined exponent. There are essentially three types of impacts to be considered. These are elastic impacts, completely inelastic impacts, and inelastic impacts enhanced by the expulsion of material from the crater which increases the momentum imparted to the crystal. For elastic impacts $K = 2$ and $\alpha = 1$. For the completely inelastic case K and α would both be unity. The third type of impact is probably the most applicable in the present context and is certainly the most difficult to interpret. R. L. Bjork, quoted by Dubin,[7] contends that the momentum contribution from expelled material may be as much as two and one-half times the momentum of the impacting particle at 70 km/sec. Although it is probably an oversimplification of the case, the assumption has been made that K is a constant over the experimental range and that the velocity dependence is contained completely by the exponent α.

The data are presented in two forms. In Fig. 2 the microphone output signal is normalized to the particle mass and plotted as a function of impact velocity. Since the particle parameters are near the limiting sensitivity of the microphone system, the data points exhibit considerable scatter which prohibits precise measurements. However, the trend of the data is obvious. A line drawn through the data points by eye as shown yields a value for α of 1.7. This is in contrast to $\alpha = 1$ for momentum dependence and $\alpha = 2$ for an energy dependence.

The data from Fig. 2 are replotted in Fig. 3 to more adequately demonstrate the departure from the commonly assumed momentum dependence. Here the magnitude of the microphone output signal is plotted against particle momentum. An independent momentum calibration point was obtained by dropping plastic beads weighing approximately 100 micrograms on the face of the crystal from a known height. This was done in air, but no drag corrections were made nor was the coefficient of restitution taken into account. However, the computed momentum was good to about 10% which is sufficient for comparison purposes. Using this point and the

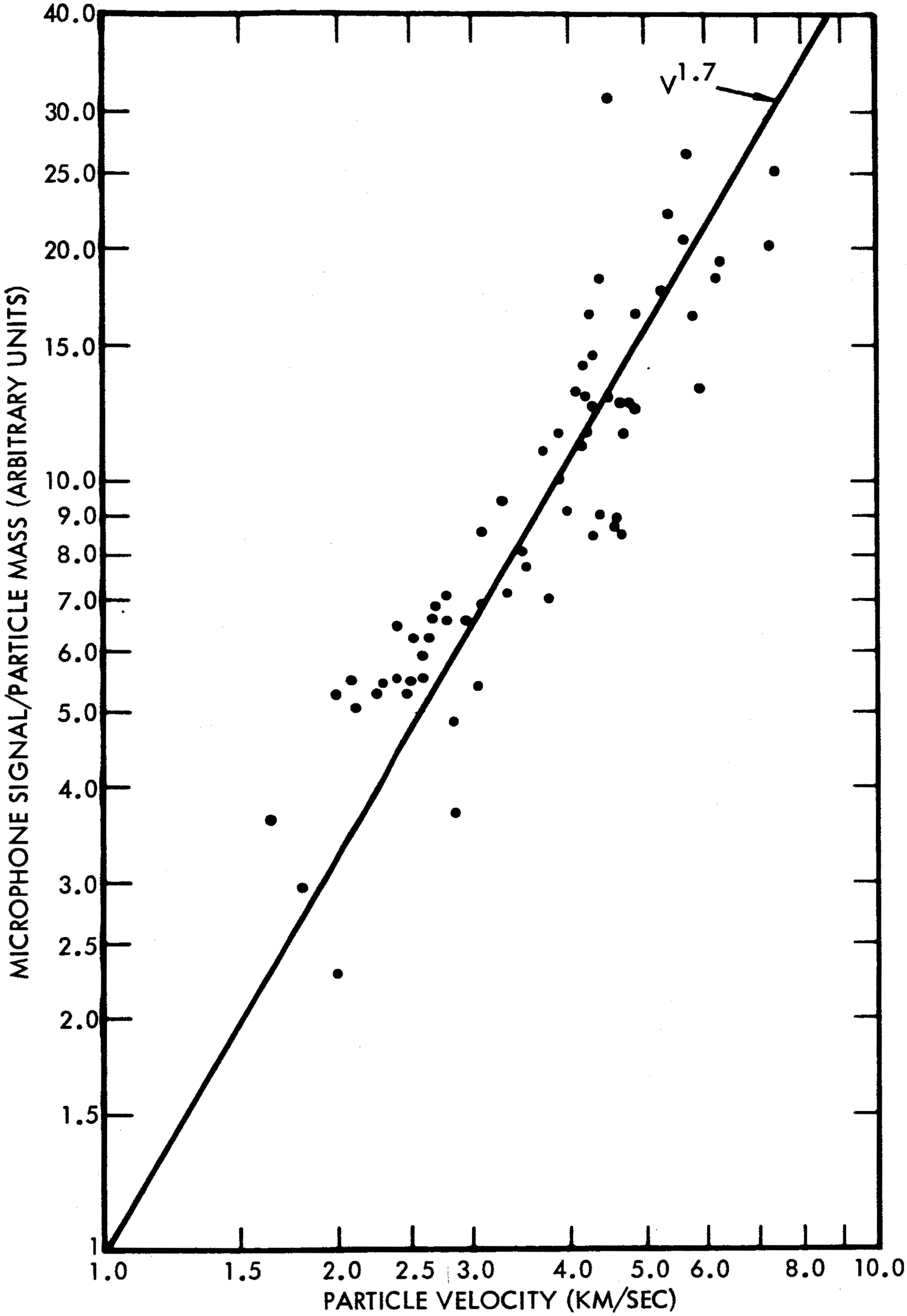

Figure 2. Amplitude of Microphone signal normalized to particle mass plotted as a function of impact velocity.

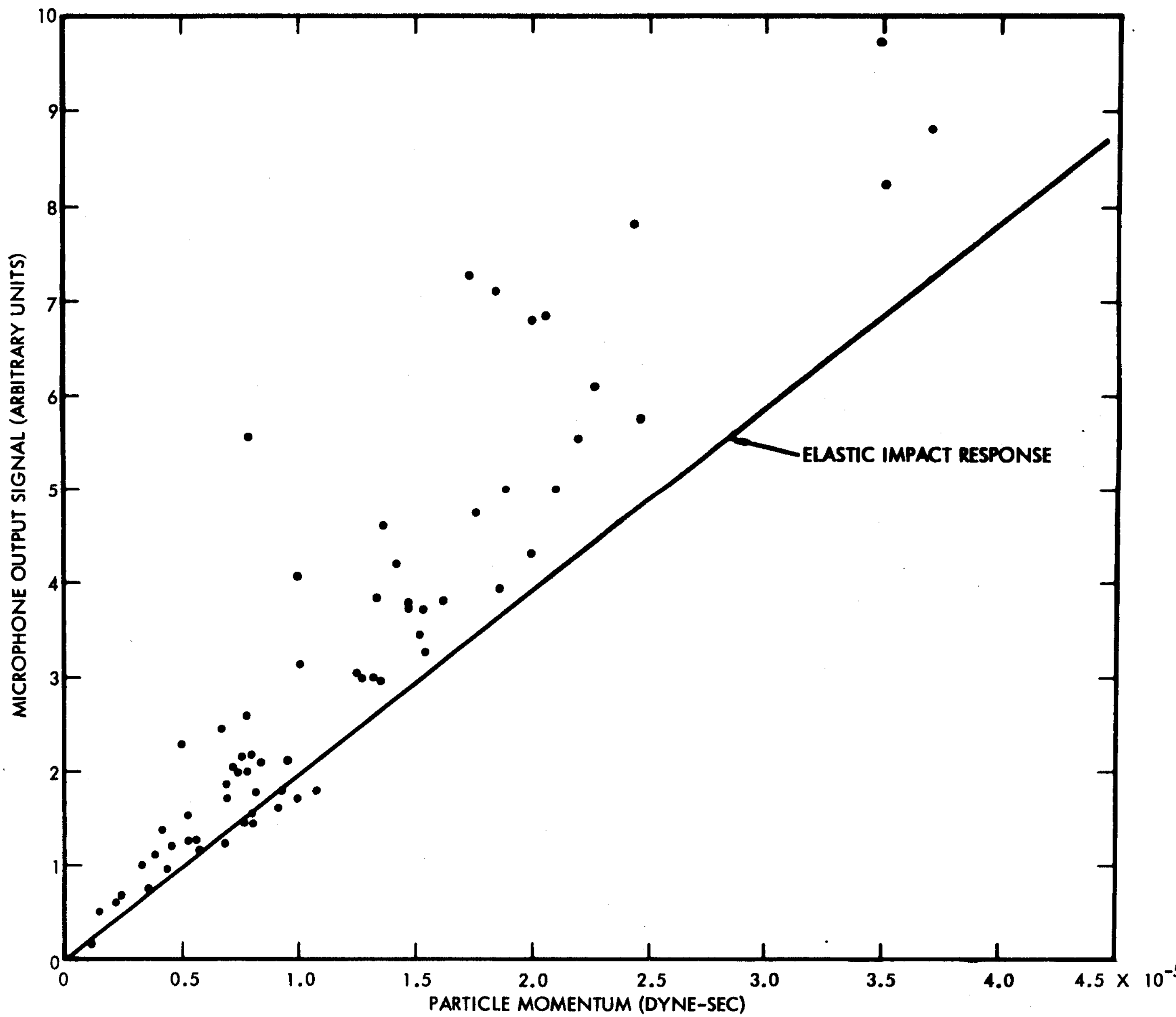

Figure 3. Output Pulse Amplitude of the Microphone Detector vs. the momentum of the impacting particle.

origin as the other, the elastic impact line corresponding to the transfer of two units of momentum was drawn on the graph. Nearly all of the data points obtained with high velocity particles lie above the elastic impact line. This indicates that the ejected material imparts at least as much (and in most cases more) momentum than does the impacting particle over the velocity range covered.

IV. SUMMARY

Although considerable modification of a typical microphone detector was required in order to obtain measurable signals, the results of the measurements described above are quite general in nature. The results imply that the response of microphone detectors cannot be characterized as simply momentum or energy dependent. In order to more fully assess the situation, a much more detailed study should be conducted. On the other hand, the empirical approach, such as that utilized here, provides information which should be considered in the analysis of data from flight experiments.

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