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A LINEAR DISPLACEMENT TRANSDUCER FOR SEVERE ENVIRONMENT APPLICATIONS

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A LINEAR DISPLACEMENT TRANSDUCER FOR SEVERE ENVIRONMENT APPLICATIONS

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ABSTRACT

A linear displacement transducer has been developed to provide both active and passive impulsive measurements of small material samples exposed to nuclear radiation. The transducer is designed to operate in an underground nuclear blast environment where sample velocities to 200 in/sec and high accelerations are encountered. Actively, the transducer provides a pulse-amplitude-modulated analog output signal for recording of linear displacement with time data. Crushable honeycomb is utilized to provide a passive measure of the kinetic energy of a moving mass. Secondary honeycomb crush due to shock loading of the transducer support structure is limited by the application of a unique self-locking design feature. Design innovations to facilitate shipping, handling, installation and field calibration are incorporated into the transducer configuration. Transducer performance is evaluated under controlled laboratory conditions.

INTRODUCTION

The purpose of this paper is to describe the pulsed E-core transducer (P.E.T.) linear displacement gage used to measure the velocity of small samples of metals exposed to underground nuclear explosions. The P.E.T. gage is designed to minimize the number of associated downhole cables, maximize signal to noise ratio, and to operate with approximately five times less power than required for earlier models. The transducer operates on the principle of changing the coupling of a transformer and amplitude modulating the incoming pulse.

Pulse amplitude modulation is used to monitor the position of each transducer at known time intervals. Dynamic output from the transducer is in the form of digital amplitude vs. time. When combined with a static calibration curve (digital amplitude vs. displacement) a curve of displacement vs. time is obtained from which sample velocity and impulse can be obtained. The P.E.T. gage is part of a relatively complex data gathering instrumentation system for underground nuclear tests incorporating multiplexing, analog to digital conversion, and digital data recording equipment. Fast pulse amplitude-to-digital conversion equipment store all information on magnetic discs located in an instrument trailer. A discussion of the associated electronic instrumentation for the P.E.T. gage is given in references 1 and 3.

The P.E.T. gage was developed through the combined efforts of both the Mechanical and Electrical Engineering Departments of the Lawrence Livermore Laboratory. This transducer, used in Mint Leaf and other

NTS shots, has proven to be very reliable in the field. This paper addresses itself primarily to the mechanical characteristics of transducer design. Electrical characteristics of the P.E.T. gage are presented in reference 2. The principle of transducer operation is discussed first, followed by a description of transducer characteristics and construction.

TRANSDUCER CHARACTERISTICS

The instrumentation developed for impulse measurement in the nuclear environment utilizes a pulsed E-core transducer (so named because of its operating principle) plus multiplexing networks, signal conversion and recording equipment, and interconnecting cables. This transducer is exceptionally qualified for underground tests because of certain characteristics inherent in the system concept.

1. The transducer provides good noise immunity by operating with large amplitude (~ 100 volts), short duration pulses ($0.3 \mu\text{sec}$) and a maximum output signal level of 20 volts. By powering four transducers with one cable and multiplexing the outputs of many gages onto one 50 ohm data line, the use of expensive downhole cables is minimized. Up to ninety transducers have been multiplexed onto one data line. Because the P.E.T. gage does not require a radiation sensitive transistorized power supply that earlier models utilized, the power unit can be located in a tunnel alcove. Installation of the power unit in this location permits about 80% fewer downhole cables.
2. The transducer is sufficiently rugged to survive the pulsed radiation exposure and large electromagnetic pulse. Sample cup velocities approach 200 in/sec and high accelerations are encountered. The P.E.T. gage is limited in this respect only by the strength of the material from which it is constructed. The transducer is so designed that displacement measurements for static calibration can be made using a dial indicator or scale. Dynamic performance evaluation tests have been performed at LLL using a ball drop tower and a ball pendulum to provide sample cup velocities to 200 in/sec and impulse measurements to 40 ktps.
3. The transducer is capable of resolving sample cup displacements to about .01 inches (dependent upon vane configuration) over the measurable length of cup travel ($\sim .75$ inch). Accuracy of measurement is determined by the accuracy used in establishing the static calibration curve, and external equipment stability.

Figure 1. Pulsed E-Core Transducer Assembly

Figure 2. Pulsed E-Core Transducer Disassembled

PRINCIPLE OF OPERATION

The pulsed E-core transducer, Figure 1, is a multiplexed linear displacement transducer capable of providing both active and passive impulse measurements of materials exposed to nuclear radiation. Actively, the P.E.T. gage senses linear displacement of a moving mass with time to provide a pulse-amplitude-modulated (PAM) analog-signal output. The gage utilizes crushable honeycomb, Figure 3, to provide a passive measurement of the kinetic energy of a moving mass which can be related to impulse.

The P.E.T. gage is basically a transformer consisting of two wire-wound ferrite E-cores. The coupling between primary and secondary windings is controlled by inserting a non-magnetic copper vane in an air gap between the two E-cores. The primary to secondary coupling is proportional to the area of the air gap not blocked by copper. At one end position there is maximum coupling between one E-core and minimum across the other. As the vane moves the roles of the two cores change giving a potentiometer or ratio action which presents a more uniform load to the transducer power supply. When current pulses are passed through the primary coils surrounding the E-cores a magnetic field is created. As the non-magnetic copper vane is moved in a direction perpendicular to the flux lines of the E-cores, eddy currents are generated in the vane which are proportional to the displacement of the vane. These eddy currents in turn set up a magnetic field which is opposed to that produced by the coils. The superposition of the two fields reduces the effective inductance of the coils and cause a variation in the magnitude of secondary output current. The variation with vane position of secondary current appears as a change of voltage at the output terminals.

TRANSDUCER CONSTRUCTION

A view of the disassembled P.E.T. gage is shown in Figure 2. The design and construction of each principle component is described below:

Transducer Body

The transducer body is constructed of injection molded diallylphthalate which was chosen because of its exceptional physical stability. Close tolerances on the E-core mounting slot width and slot location is provided to assure good alignment of the E-cores. The E-cores located in each body half must be directly opposite each other when the halves are brought together. The body halves are aligned with respect to each other by two dowel pins.

E-core

E-cores are made from ferrite, a combination of magnesium, iron, and zinc oxides, and are commercially available in all shapes and sizes. The E-cores used in the transducer are purchased from the Ferroxcube Co. under the number 812 E 250. The commercial E-cores have three posts the same height. In order to allow a vane to slide between the center posts, the center post must be machined using a diamond grinder. After machining the center post is wrapped with 25 turns of 30 gage copper wire. Silastic Resinbond 907 is used to bond the E-core sides to the transducer body. While the silastic is drying, an alignment fixture is used to hold the E-cores in the desired position. The outer posts are .005 inches above the transducer body, assuring good contact of the E-core posts when the transducer is assembled. No silastic is allowed under the E-cores so that the E-cores are allowed to move up and down as required for assembly. Electrical leads from the E-cores are passed through holes in the transducer body and exit through the backplate of the transducer.

Vane and Vaneholder

The vane was designed by the LLL Electrical Engineering Department. The moving vane is made from thin printed circuit board with a pattern etched in the copper. Output amplitude versus position is determined by the shape of the pattern. The vane can be shaped to give, in effect, a semi-digital output, a linear output, or a response that gives higher resolution to parts of the travel that are of most interest. In order to obtain repeatability of the transducer output, the tolerances on the vane are held rigid. To accurately position the vanes in the vaneholder, an alignment fixture and the vane bonded in place, using Resinbond Adhesive 907. Accurate positioning of the vane assures good repeatability of the static and dynamic outputs of the transducer. The vaneholder is machined from 6061-T6 aluminum.

Bearing and Shaft

The bearing is a Thompson Ball Bushing, A-61014-SS, which is of corrosion resistance stainless steel construction. Friction coefficient of the ball bushing varies from .001 to .004. The shafts used with the transducer are of two types, heavy and light construction. The heavy shaft is SAE 51440C steel case hardened to 50-55C Rockwell for good bearing surface. The light shaft is 6061-T6 aluminum which is hard anodized. Both shafts have a diameter of 0.3740 to 0.3755 inches.

Electrical Components

Electrically, the transducer has very simple construction consisting of two sets of E-cores and two resistors. One set of E-cores and one resistor comprise a dummy circuit for stability. By utilizing two sets of

E-cores, the amount of copper under the E-cores remains constant, giving a more stable output than a varying amount of copper. Since one E-core circuit is a dummy circuit, the electrical circuit is different on each half of an assembled transducer. The resistors are mounted externally on the gage body. For protection of the resistors and adjacent electrical wiring during handling and gage assembly they are covered with silastic. Details of the P.E.T. gage electrical circuit are given in reference 2.

Ball Plungers

Two ball plungers locate the vaneholder in the forward position to provide a calibration checkpoint. Positioning the cup full aft against face of honeycomb provides a second calibration check point. The ball plungers are adjusted to require 150 gms axial force to unseat and move the dynamic components of the transducer from their detent position.

Pullrod, Palnut and Palnut Retainer

The pullrod performs two important functions of limiting secondary crush due to bulkhead motion and permitting field calibration of a gage installed on a tunnel bulkhead. The pullrod engages the palnut when the cup moves aft and contacts the face of the honeycomb. After engagement any tendency for the cup to move in the opposite direction due to rebound and bulkhead motion is prevented. Secondary honeycomb crush is thereby limited to further motion of the cup in the aft direction only. If by chance secondary crush should occur the secondary crush depth will be inscribed on the pullrod by the palnut. A capnut replaces the palnut retaining nut during shipping to prevent movement of the sample cup and possible honeycomb crush.

CALIBRATION

A. Static

All displacement gages for underground tests are numbered individually. Each number corresponds to a specific mechanical engineering experiment number. Because transducer output is essentially non-linear over its measureable displacement range each P.E.T. gage is calibrated individually in the laboratory by the ILL Electronics Department. The static calibration curve (digital amplitude vs. displacement) is used to determine a curve of displacement vs. time from the transducer output (digital amplitude vs. time).

B. Field

Field calibration consists of checking an installed transducer for

TABLE I

ALUMINUM HONEYCOMB DYNAMIC CRUSH STRENGTH

Honeycomb Designation	Design Value Dynamic Crush Strength (psi)	Calibration Value Dynamic Crush Strength (psi)
1/8-5052-.002	720	1246
1/8-5052-.0007	170	187
3/16-5052-.0007	78	93
3/16-3003-.0007	55	77
1/4-5052-.0007	52	38
3/8-5052-.0007	26	19

Figure 3. View of P.E.T. Gage Showing Honeycomb Location

possible deviations from its static calibration curve at zero cup displacement (forward detent position). The sample cup is normally located at zero displacement when the transducer is installed on the tunnel bulkhead. Cup position can be verified by physically moving the dynamic components of the transducer in and out of the forward detent by means of an accessible pullrod located at the rear of each P.E.T. gage.

C. Honeycomb

All of the P.E.T. gages utilize crushable honeycomb which gives a passive measure of the kinetic energy of a moving mass. Different types of passive honeycomb are used in NTS experiments. Table I gives the honeycomb designation of six types with their dynamic crush strengths. The dynamic crush strengths were determined experimentally at LLL (4). The passive honeycomb is attached to the P.E.T. gage at the forward end of its rear can as shown in Figure 3. It is intended to be partially crushed by the sample cup during cup deceleration. As can be seen from Table I, the dynamic crush strength is a function of cell size, wall thickness, and material properties of the aluminum. The cell size is the fraction such as $1/8$, $3/16$, $1/4$ and $3/8$ given in the table. The honeycomb is fabricated from either 5052 or 3003 aluminum alloy. The thickness of the passive honeycomb is accurately measured by using an optical gage. Honeycomb is also used to provide a cushion for the sample inside the cup. The cup honeycomb area is that area which can be crushed by the sample and sample backup materials if the latter is used.

CONCLUSIONS

The development of the P.E.T. gage for underground nuclear test measurements shows promise for other applications, particularly those involving severe environments. To summarize the principle characteristics of this transducer are:

1. The pulsed E-core principle enables construction of an exceptionally rugged measuring device to survive the thermal, nuclear and electromagnetic radiation.
2. Powering the transducer with large amplitude short duration pulses and multiplexing the output signals minimize the number of down-hole cables. In addition, information data are immune to signal interference.
3. The use of crushable honeycomb enhances instrumentation reliability by providing a backup measurement of kinetic energy and impulse.

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