Lawrence Livermore Laboratory

FAST RECOVERY STRAIN MEASUREMENTS IN A NUCLEAR TEST ENVIRONMENT

W. R. Kitchen, W. J. Nauman, and D. W. Vollmer

April 30, 1979

MASTER

This paper was prepared for submittal to The 10th Transducer Workshop, Colorado Springs, Colorado, June 12-14, 1979.

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

FAST RECOVERY STRAIN MEASUREMENTS IN
A NUCLEAR TEST ENVIRONMENT

W. R. Kitchen,¹ W. J. Nauman,² and D. W. Vollmer³

ABSTRACT

The recovery of early-time (50 microseconds or less) strain gage data on structural response experiments in underground nuclear tests has been a continuing problem for experimenters at the Nevada Test Site. Strain measurement is one of the primary techniques used to obtain experimental data for model verification and correlation with predicted effects. Peak strains generally occur within 50-100 μ s of the radiation exposure. Associated with the exposure is an intense electromagnetic impulse that produces potentials of kilovolts and currents of kiloamperes on the experimental structures. For successful operation, the transducer and associated recording system must recover from the initial noise overload and accurately track the strain response within about 50 μ s of the nuclear detonation.

This paper describes a gaging and fielding technique and a recording system design that together accomplish these objectives. Areas discussed include: (1) Noise source model; (2) experimental cassette design, gage application, grounding, and shielding; (3) cable design and shielding between gage and recorder; (4) recorder design including signal conditioner/amplifier, digital encoder, buffer memory, and uphole data transmission; and (5) samples of experimental data.

1. EG&G, 680 Sunset Rd., Box 1912, Las Vegas, Nevada, 89119.
2. Effects Technology, Inc., 5383 Hollister Ave., Santa Barbara, California 93111.
3. Lawrence Livermore Laboratory, University of California, Livermore, California 94550.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

829

INTRODUCTION

The Defense Nuclear Agency in conjunction with various national laboratories and supporting contractors is engaged in a continuing series of nuclear effects tests at the Nevada Test Site. Many types of experiment are conducted during these tests, of which this report addresses only one, that of strain measurements on thermal structural-response experiments. Specifically, we describe a measurement technique and equipment we have developed to successfully make strain measurements within 50 microseconds of a nuclear detonation.

The objective of these experiments was to determine the response of simple structures or specimens to the impulse heating of the nuclear radiation. Strain measurements were the principal technique used to measure the specimens' responses. The radiation deposition time (and resultant heating) is very short compared to the structural response times of the experimental specimens. This results in an impulsive loading that excites the resonant frequency of the specimen. Associated with the radiation exposure is an electrical overload resulting from an intense electromagnetic impulse that produces potentials of kilovolts and currents of kiloamperes on the specimens. To obtain a successful measurement, the transducer and associated recording system must survive and recover from this overload before the peak strain in the specimen occurs.

TEST SITE DESCRIPTION

The Nevada Test Site is located about 60 miles northwest of Las Vegas, Nevada. The tests are conducted underground in tunnels drilled into the side of Rainer Mesa. Typically, the tunnels extend about one mile into the mesa in a horizontal plane at an overburden depth of 1000 to 1500 ft. Signal cables are routed from the experimental areas through vertical drill holes to the mesa surface, where instrumentation vans house the recording systems. Figure 1 illustrates the physical layout of a tunnel. On a typical test, as many as 1000 data signals may be transmitted over several hundred cables to the instrumentation vans. Typical cable length from transducer to surface recording system is in the range of 3000 to 4000 ft. To insure against radioactive gas leakage to the atmosphere, blast doors and gas seals are placed in the tunnel and gas seals are installed in the cables. For twisted shielded pair (TSP) cable such as might be used for low-level analog signals, gas seals are constructed by separating the conductors and shields into individual wires and filling the area around the wires with epoxy. This results in a break in shield integrity and a severe noise injection point for TSP cables.

The experiment structures are emplaced in Line-Of-Sight (LOS) pipes that extend from the nuclear device down the tunnel as far as 1000 ft. These LOS pipes are designed to enclose a solid angle of the radiation emitted by the device. That is, beginning with a relatively small diameter at the device, they increase diameter at a constant rate so that any cross-section area within the pipe has a direct line-of-sight to the radiation source. The pipes are designed to be gas-tight and are evacuated during the test. Experiments are mounted within the pipe on bulkheads placed across the pipe at several locations along its length. This provides several levels of radiation exposure. Signal cables from the individual experiments are routed behind the bulkheads and through the LOS-pipe wall at vacuum ports. From the

Figure 1. Layout of test tunnel at Nevada Test Site.

vacuum ports, they go directly to the instrumentation systems on the mesa surface or, at the experimenter's option, to instrumentation alcoves in the tunnel. These alcoves generally are located within 100 to 300 ft of the experiment station and are used for conditioning the data signals prior to transmitting them to the mesa surface. Figure 2 is a diagram of a typical experiment station and alcove.

EXPERIMENT DESCRIPTION

Underground tests are conducted infrequently and at high cost, so radiation-exposure area is at a premium. This dictates the use of as small a structure or specimen as practical. The specimens tested in these experiments consisted of rings, cylinders, beams, and annuli and were on the order of ten inches in largest dimension. These small sizes result in high resonant frequencies. Also, because most of the information is contained in the first peak of oscillation following the impulsive load, fast recovery of the recording system is imperative. For the structures we tested, this initial peak typically occurred within 50 microseconds of the radiation deposition.

Figure 3 shows a ring specimen in its cassette or container. The radiation exposure was on the right surface of the ring. The radiation shields imbedded in the foam block prevent excessive heating of the strain gages.

Figure 2. Experiment station and alcove.

Figure 4 shows four beam specimens in their mounting block, which mounts into a cassette similar to that illustrated in Figure 3.

Figure 5 is a schematic illustration of five experiment cassettes at one experiment level or station. In Figures 6 and 7 these same cassettes are shown in place in the LOS pipe. Figure 7 shows the cable junction box behind the bulkhead, the zipper tubing for cable protection, and the vacuum feedthrough for exiting the cables from the LOS pipe.

ZERO-TIME NOISE SOURCES

The major problem in fielding this type of experiment is the electrical overload and consequent data loss from zero-time electrical noise in the

Figure 3. Ring specimen in cassette.

Figure 4. Beam specimens in mounting block.

Figure 5. Five experiment cassettes in test configuration.

measuring system. This noise is produced initially by the device radiation-emission and has a very short time-duration compared to typical time constants in the measuring system. Thus, the noise initially appears as an impulse. Depending on the design of the system, the strain level, and the radiation exposure level, the data loss will extend from a few tens of microseconds to as much as one millisecond. Figure 8 shows what we believe to be the three predominant noise sources in these experiments:

Noise source 1 is the photon-induced surface emission of electrons for the experiment structure, the LOS, and the bulkhead. Neglecting loss and limiting effects, one can calculate very high potentials produced by this emission. However, as indicated by experimental measurements, space-charge limiting generally restricts this potential to about 5E volts. Its rise-time is at least equal to the radiation deposition rate; its fall-time is determined by the electromagnetic (EM) properties of the structure and normally is oscillatory. This effect occurs throughout the experiment structure, and is relatively proportional to the photon deposition and

5 cassettes
of interest

Figure 6. View of
experiment cassettes
in test configuration.

Shielded
vacuum
feedthru

Cable port

Junction box

Mounting
bulkhead

Cassettes
(hidden)

Figure 7. Back view of
mounting bulkhead.

Figure 8. Zero-time noise sources.

material density in both the metallic and dielectric materials of the structure. Also, although dielectric materials exhibit some conductivity during the deposition time, they recover quickly. Thus, a well-isolated component internal to the structure can become electrically charged and maintain that charge for a comparatively long time.

Noise source 2 is the photon-induced charge transfer within the cables that are internal to the LOS. This is the same effect as identified above, but because the cables normally are well shielded by the bulkhead, only the most intense photons penetrate to them. In a typical experiment, this source produces potentials of a few tens of volts in the cables. The rise-time of this noise is a function also of the deposition rate; its duration depends on the exposed cable length, the terminations at the cable ends, and the type of cable. In general, this source produces a large noise energy in the cable and this must be dissipated prior to transmission of valid data. Additionally, since the surface emission effect also occurs on the outside surfaces of the cable, if the cable ends are not closed or shielded this noise can radiate into the signal paths internal to the cable.

Noise source 3 is the induced noise in the cable system between transducer and recording system. It is the result of EM fields produced by replacement currents, other signal cables, power cables, ground wires, etc. The magnitude, frequency, and duration of this noise are highly dependent on the size and length of the total cable plant. On typical experiments, measurements made on the outer shields of signal cables indicate this noise can be on the order of several hundred volts and tens of amperes, with frequency components in the 10 to 100 KHz range and durations of several hundred microseconds on the mesa-surface end of the cable plant. Of the three sources, this is the most conventional and is present to some extent in any large cable system. It is, essentially, the impulse response of the cable plant.

DESIGN PHILOSOPHY

Using the above noise model, we have designed a gaging and fielding technique and recording system to minimize noise effects while providing a reasonable economic compromise and fielding ease when compared to techniques currently being used. We have attempted to minimize the effects of noise source 1 by means of experiment cassette design, gage selection and application technique, and gage-shielding design. The cassettes are designed as closed EM boxes, using aluminum where possible and with all internal components tightly grounded to the box. The use of aluminum minimizes free charge generation, and grounding minimizes the recovery times of electrical circuits within the box.

The front of the box is covered with a thin metal diaphragm, allowing radiation to pass through but acting as a barrier to EM fields and preventing the escape of free surface charge from the inside of the box.

Specimens within the cassettes are mounted in foam or on tracks with foam stops, as appropriate, to allow free structural response but prevent extraneous damage. Where the mounting technique results in electrical isolation, the specimen is grounded to the cassette with flexible straps.

To maximize transducer output and transducer symmetry to both radiation deposition and noise pickup, two active arm configurations are used. Gages are of 0.25-in. square metal foil and are large enough to allow continuous use of 10-V bridge excitation. Identical gages are used for the completion arms; they are mounted on small samples of the specimen material that are mechanically isolated from the specimen but in intimate electrical contact with it. The use of 120-ohm gages provides an approximate match to the cable impedance and minimizes the time constant formed by the cable capacitance and gage resistance. The minus excitation point of the bridge is electrically tied to the specimen and cassette, to reference the gage signal to the cassette common and minimize charge buildup between gage elements and their mounting surface. Figure 9 shows the bridge wiring.

Finally, all active and completion gages and all cable terminations are covered with aluminum foil shields that are electrically tied to the experiment surface they cover. This provides a tight EM shield for the gages and prevents electrons emitted from other surfaces within the cassette from being picked up on the gages or terminations.

To minimize the effects of noise source 2 and noise source 3 on the cable from the experiment to the instrumentation alcove, we use a special TSP cable and feedthrough connectors at the vacuum ports on the LOS. The cable is Trompeter QRC-78-2, a single, well-balanced twisted pair with two concentric, separately insulated braided shields.⁴ The shields carry excitation to the gage, and the signal is returned on the pair. The outer shield (the minus excitation point of the bridge) is tied to the cassette, so that the foil shields described above become extensions of the cable shield. The vacuum port connectors maintain the integrity and isolation of the cable shields through the vacuum port. These connectors are a special Quadrex connector manufactured by Trompeter. All signal cables exiting an experiment cassette are grouped together and enclosed in an insulated braid

4. Reference to a company product or name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

Figure 9. Bridge wiring.

zipper tubing tied to the cassette so it is an extension of the outer surface of the cassette. The vacuum port was designed to maintain the integrity and isolation of the zipper tubing through the LOS wall.

At the instrumentation alcove, typically 100 ft from the experiment, all instrumentation supporting a cassette is housed in an isolated, enclosed rack. At this end, the zipper tubing is tied to the rack, and the cassette, zipper tubing, and alcove rack form a completely closed shield system. All internal electrical transmission path time-constants or RC decay times are at least a factor of 20 less than the desired zero-time recovery.

To minimize the effects of noise source 3 in the uphole cable run (the signal cable from the instrumentation alcove to the mesa-surface recording system), we designed a Digital Encoding and Storage System (DES) that encodes and temporarily stores the high-level analog data in the alcove, then transmits it uphole to the mesa surface for permanent recording. Thus, the data transmitted uphole is at a high level, in a frequency spectrum with better immunity to cable-plant noise and delayed in time until the noise has decayed away.

To amplify the transducer signals to a level acceptable to the DES system in the alcove, we use commercial Ecktron instrumentation amplifiers. These units are high-performance combination amplifiers and excitation power

supplies capable of withstanding an input pulse in excess of 1000 V and recovering in less than 25 μ s. For our experiment, typical gains were in the range of 500 V. Figure 2 illustrates these design details.

DIGITAL ENCODING AND STORAGE SYSTEM

System Description

The DES system digitizes transient analog signals at a high rate, stores the samples in a local memory, then transmits them to a remote recording facility at a slower rate. The system comprises two types of chassis--a four-channel encoder chassis and a formatter chassis. Each encoder chassis contains the analog-to-digital conversion circuitry and memory for four input channels. The formatter provides power and control for the encoders and formats the data from the encoders into a PCM-bit stream suitable for transmission. Up to eight encoders (32 input channels) can attach to one formatter. Coupling between encoders and formatter is by TSP cable, not exceeding 10 ft in length. Figure 10 illustrates a typical use of the system.

Encoder Description

Each encoder chassis contains a logic board, a memory battery, four A/D boards, and four memory boards. The logic board contains the timing, sampling, interfacing, and memory readout logic, together with the battery control and charging circuitry. The logic board is common to the four input

Figure 10. Digital Encoding and Storage (DES) System.

Figure 11. Block diagram of memory system.

Figure 1. Top view of the device.

Figure 2. Front view of the device.

1.1.1. Description

The device is a portable, self-contained, and self-powered unit. It is designed to be used in the field and is capable of operating for up to 10 hours.

The device is connected to the host computer via a standard RS-232C interface. It is also capable of operating as a standalone unit.

encoders and the formatter. It includes a battery backup that allows readout of the encoder memories after failure of the ac input power. The battery provides sufficient power to operate the readout logic for approximately 15 s (20 memory scans) in the absence of ac power.

The interface board provides isolation and coupling between the system and the remote control and monitor signals and the output PCM-bit streams.

The logic board contains circuitry to sequentially address the encoder memories, read the data stored in them, and format them into a serial stream. It then adds frame synchronization, memory address, and status information and converts the stream into a Bi ϕ L format suitable for transmission on 50-ohm coaxial cable. The output bit-rate is 1.228M bits, suitable for recording on a conventional analog tape transport operating at 120 ips.

The logic board also contains circuitry to locally decode one data channel and display its value in decimal as well as analog form. This information is available on the front panel of the formatter for setup and checkout use.

Figure 14 is a simplified block diagram of the formatter and Figures 15, 16 and 17 give three views of it.

Figure 14. Block diagram of formatter.

Figure 15. Formatter, front panel.

Figure 16. Formatter, rear panel.

System Operating Modes

Figure 18 illustrates the operating modes of the system. These modes primarily pertain to the encoder; the formatter under all conditions constantly cycles through the encoder memories and transmits the currently stored data. The individual modes are described below:

Protect Mode. From any power-up, the system automatically enters the Protect mode where the memories are protected, that is, they cannot be loaded without a manual reset.

Figure 17. Formatter, top view.

Ready Mode. A manual reset shifts the system to the Ready mode, in which the system will accept remote or local calibration commands. Upon receipt of a Calibrate signal, the A/Ds begin converting and loading the data into memory. The memory location written into is just ahead of the address location currently being read by the formatter. Thus, the input data are encoded and shifted through the memories at a sampling rate equivalent to the formatter framing rate. In this manner, all memory locations are checked during a complete memory scan of the formatter.

Armed Mode. Upon receipt of an Arm signal, the system enters the Armed mode regardless of the condition of the Calibrate signal. In this mode, the system will accept Trigger pulses. If the Arm signal drops before receipt of a Trigger, the system will return to the Ready mode and ignore any Trigger signals.

Figure 18. System operating modes.

Load Mode. Upon receipt of a Trigger signal while Armed, the system enters the Load mode. The system latches and thereafter ignores any change in operational commands. It loads the memories at the predetermined rates, and after memory load is complete, the system automatically enters the Protect mode and remains in this mode until manually reset.

Auto Reset. In the Auto Reset mode, the system operates and loads as described above except that upon completion of the load cycle, the encoders automatically reset to the Ready mode. Thus, upon receipt of subsequent Arm and Trigger signals, a new load cycle will be initiated. This mode is primarily for use during setup and checkout, as the data are not protected and could be lost if false Triggers occurred during an experiment.

TEST RESULTS

To verify proper operation of our recording system and to provide a base line for zero-time recovery and noise measurements, we included control or dummy gages at each experiment station. These control experiments were identical to the active experiments except they were designed to receive no strain input. Figure 19 illustrates the response of the control gage at level C. Figure 19(a) is a tracing at 250 μ s per marker and Figure 19(b) is at 40 μ s. As indicated, we were not entirely successful in maintaining complete strain isolation. The initial spike or pulse is the impulse-response of the entire system to the electrical input generated by the radiation

Figure 19. Control gage, Level C.

deposition. Note that this exists for approximately 40 μ s and is the system recovery time. Following this is the structural response of the specimen. In this instance it is a 100 microstrain peak ring-down of the control. Typical peak strains on active experiments at this level were in the 5000 microstrain range; this represents a 2% effect and does not invalidate use of the control to verify proper system performance.

Figure 20 illustrates the response of a cylinder specimen also at experiment level C. Figure 21 illustrates the response of a ring specimen at experiment level B. The response of the ring begins almost immediately after it is shocked, so the recording system was not able to return to baseline prior to the beginning of the ring response. Figure 21(a) is particularly interesting in illustrating the absence of long-term noise in the data. The peak strain in this specimen was slightly less than 500 microstrain; this is equivalent to 5 mV at the transducer. Figure 22 illustrates the response of a cylinder specimen at experiment level B. Figure 23 illustrates the response of a beam specimen at experiment level A. Because of failure of the cable running from this experiment level to the recording system on the mesa surface, these data initially were lost. However, by reentering the tunnel several days after the test and physically recovering the DES System encoders, we were able to extract the data from the encoder memories. Thus, the backup capability of the memories prevented the loss of data from this experiment level.

Figure 20. Cylinder, Level C.

Figure 21. Ring, Level B.

Figure 22. Cylinder, Level B.

Figure 23. Beam, Level A.

CONCLUSIONS

The fielding techniques and equipment we have developed allow reliable recovery of low-level strain data on underground nuclear tests. Specifically, we have obtained laboratory-quality recordings of strain levels of less than 500 microstrain within 50 μ s of the nuclear detonation. This equipment requires fewer uphole cables and significantly less fielding effort than do conventional FM recording techniques.

ACKNOWLEDGEMENTS

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under contract No. W-7405-Eng-48. We wish to thank Mr. S. Weld, ETI, for his efforts in the design and fabrication of the experiments; Mr. J. Slater, LLL, for his efforts in the design of the Digital Encoding System, and Mr. F. Quintana for his efforts in the construction and fielding of the DES. Special thanks go to Mr. D. Kohler, Program Officer, Aero Space Sys., DNA, without whose enthusiastic support this development effort would not have been possible.