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UCRL - 73427
PREPRINT

CONF-720417--1

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**DIAGNOSTIC PROBLEMS RELATED TO MEASUREMENTS
NEAR UNDERGROUND NUCLEAR DETONATIONS**

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February 23, 1972

**This paper was prepared for presentation at The 7th Transducer Workshop,
Albuquerque, New Mexico, April 4-6, 1972**

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DIAGNOSTIC PROBLEMS RELATED TO MEASUREMENTS
NEAR UNDERGROUND NUCLEAR DETONATIONS*

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ABSTRACT

Problems associated with measuring data related to containment of underground nuclear detonations are very difficult to overcome, particularly with a line-of-sight pipe from the detonation. Measurements of pressure, temperature, radiation, acceleration, particle velocity, and shock position are routinely fielded; we have also attempted measurements of other variables, such as gas density and optical transparency or brightness. One must have a system that can survive high radiation levels, high shock loading, large electromagnetic noise pulses, and blast conditions; a system with frequency response in the 50-100 kHz region, while having 1500-4000 ft of cable between the transducer and the electronic recording equipment, is also required. The reliability and dynamic range of the system must be large, since channel limitations do not often permit much redundancy. Contributing to the problem is the poor predictive capability for many of the variables, particularly along a line-of-sight. Dynamic calibration of pressure and temperature sensors is necessary for understanding the data, and a particular problem is the inability to measure stagnation properties and flow velocities

*Work performed under the auspices of the U.S. Atomic Energy Commission.

behind the first arrival. The current practices at LLL with regard to transducers and cables are discussed, along with the shortcomings of the present capability.

INTRODUCTION

A nuclear explosion creates a severe environment in which transducers must function. Pressure, temperature, radioactivity, and electromagnetic interference levels are very high, and their time-derivatives (frequency contents) are also large. In this paper I discuss some problems encountered in diagnosing the effects of underground detonations and in diagnosing the response of related hardware. Determining the performance of the explosive itself is a different topic, which will not be considered.

Most of the material reported herein is from experience with line-of-sight (LOS) experiments, in which a pipe leads from the source to various exposure stations. After irradiation, the pipe must be closed to prevent blast damage or other damage to the experiments and to prevent release of radioactive debris to the environment. Detailed diagnostics are required to document the performance of the system, to provide design criteria for future systems, and to compare performance with calculated behavior.

The various parameters will be discussed individually. Some problems associated with the measurements will be pointed out, and some desirable measurements that are not now feasible will be mentioned.

GAS-PRESSURE MEASUREMENTS

Gas-pressure measurements cover a wide range of conditions from blast pressure in the 10^4 -psi region to quasistatic measurements in the few-psi region. All transducers are required to be very insensitive to shock, radioactivity, and temperature, if good data are to be obtained.

Figure 1 shows the measured acceleration, temperature, and radiation at a location where a pressure measurement was required. (The problems associated with obtaining the data in Fig. 1 will be ignored temporarily.) Acceleration of 500-700 g, gas temperatures to $\sim 1100^\circ\text{C}$, and radiation levels of 10^5 - 10^8 R/hr make up a severe environment for a pressure transducer. Figure 2 shows the output of three pressure transducers subjected to the environment; Fig. 3 shows the output from two transducers that experienced the radiation and acceleration, but not the heating. The end of the data is presumably the result of cable damage rather than transducer damage, but the cause cannot be firmly established. The data were all recorded with a 0-20 kHz bandwidth, except for a 0-4 kHz bandwidth for the radiation data in Fig. 1.

As can be seen, the pressure records tend to correlate more with the accelerometer than with each other. The temperature, about 1100°C , is far above the normal range for the great majority of pressure transducers. Obviously there is no good pressure record from the location under discussion. In Fig. 3, one transducer appears to have a usable output, but the other is clearly suspect: it shows negative pressures. Comparison of the two records shows that, except for polarity, they are similar, and the seemingly good

record becomes questionable. These two records were from 1000-psia units with a specified shock sensitivity of 0.001% of full scale per g-unit. The early noise from about 10-45 msec is nearly 10% of full scale, implying accelerations approaching 10^4 g. Apparently the transducer shock sensitivity is at least an order of magnitude above specification; other problems, however, such as cable noise due to shock, may contribute or even dominate, since the signal in question is only about 20 mV.

Because of economic constraints that manifest themselves as limitations in recording capability, one transducer may be required to serve as a blast-pressure transducer and also as a quasistatic pressure transducer, often for superheated steam.

Figure 4 shows two relatively long-term pressure records obtained at the same location. The divergence of the records at late times could be the result of inadequate temperature compensation, radiation effects, or a combination of these and other factors.

Electromagnetic energy coupled into the diagnostic system can result in anything from a spike of a few tens of microseconds duration to destruction of the transducer or signal-conditioning hardware. Figure 5 is a photomicrograph of a foil gauge element on a transducer, damaged at zero time. Similar damage resulted when a 1- μ f capacitor charged to 500 V was discharged through a gauge element, although, in practice, the breakdown appears to be between the element and the case. Grounding at the transducer and floating of the recording system have minimized such occurrences.

TEMPERATURE MEASUREMENTS

Temperature data are required for several applications and range from dc measurements with $\pm 0.5^{\circ}\text{C}$ accuracy near room temperature to fast measurements of over 1000°C where accuracy to within 10% would be quite acceptable. Thermistors, while sensitive to shock and radiation, generally work well for the dc measurements. The blast measurements can be made with either thermocouples or resistance thermometers. Resistance thermometers have been unsatisfactory because the film is prone to damage when mounted for a blast measurement. The thermocouple is most used; the presently used design is a coaxial couple with the tip slightly recessed. The problems with thermocouples are the relatively low signal levels and the difficulty in getting a reference junction that can withstand the shock, radiation, etc.

RADIATION MEASUREMENTS

Radiation data are obtained with an ionization chamber that has an electrometer tube mounted inside the chamber. Data are considered to be good to about $\pm 50\%$, but the detector has a usable range of about 10^8 with a logarithmic output. The two main problems with the system are shock sensitivity and drift. Because of the wide dynamic range, a small drift may be a factor of 2 or more in apparent radiation level. Significant accelerations will make the output go negative (relative to increasing radiation); and, because of the extremely high impedance of the chamber-electrometer system, recovery may take as long as a minute. Fortunately,

radiation speeds recovery; and, in a high radiation field ($>10^3$ R/hr), recovery can be as fast as a few milliseconds. In such cases the record merely appears noisy, as in Fig. 1. The most significant complication occurs in determining the arrival time of a modest radiation level, since separating natural recovery from radiation-induced recovery is not always simple, as can be seen in Fig. 6. The large dynamic range makes the system attractive, even with its shortcomings.

ACCELERATION AND VELOCITY MEASUREMENTS

Accelerometers and velocity gauges are generally of the carrier-system, variable-reluctance type. These systems are relatively immune to electromagnetic-pulse interference and to radiation damage, and they have proved to be very reliable below a few hundred g and below a few hundred feet per second. Their major shortcoming is their upper frequency limit of about 500 Hz.

Piezoresistive accelerometers are also used, particularly where frequency response is important. These accelerometers have functioned well, although they are susceptible to electromagnetic-pulse noise or damage. Complete loss of a data channel at zero time is occasionally observed, as is a zero shift. A sensitivity shift has been suspected on a few occasions; but, in general, agreement between the variable reluctance and piezoresistive units is satisfactory. Cross-axis sensitivity is occasionally a problem with both types of transducers.

SHOCK POSITION INDICATORS

Two basic techniques are used to define arrival time. Very close measurements are usually done with shorting pins. These systems are straightforward, and the only real problem is to avoid shorting by ionization from high radiation levels. The other technique measures the position of the 0.5-1.0 kbar level by finding where a coaxial cable is crushed. The crush position as a function of time gives a shock-propagation curve; SLIFER (Shorted Location Indicator by Frequency of Electrical Resonance) and CLIFFER (Cable Length Indication Found From Electrical Reflection) are two means of locating the crush position.

The SLIFER equipment measures the cable in the tank circuit of an oscillator, and the frequency-vs-time can be converted to shock position. The CLIFFER equipment determines the cable length by measuring the round-trip time for a pulse sent down the cable. By this method a cable length is found in the manner of a time-domain reflectometer about every 9 μ sec. The CLIFFER has a digital output and is still under development. Usable cable lengths are up to 175 ft for the SLIFER and up to 300 ft for the CLIFFER. Because in both cases the cable to be measured usually goes quite near the working point, both systems are subject to loss of data from electromagnetic noise, particularly in the first millisecond. This problem has been minimized for the SLIFER by using band-pass filters. The SLIFER oscillator and the CLIFFER pulser are subject to shock-induced noise, since significant accelerations can reach the units before the cable is crushed.

MEASUREMENT NEEDED BUT BEYOND OUR CURRENT CAPABILITY

Gas density, flow velocity, stagnation parameters, and very sharply rising blast pressures are presently beyond our measurement capability. The blast-pressure problem is one of finding a radiation and electromagnetic-noise-resistant transducer with a frequency response of >200 kHz.

Figure 7 shows the output of one candidate that failed. The transducer saw a static level of ~ 150 psia, a dynamic peak of ~ 700 psia, and a radiation level roughly 10^{-3} of that in which the unit would be required to operate.

Measurement of stagnation parameters is currently impractical because of damage incurred by looking down the line of sight. Damage can be caused by x rays, neutrons, or debris. A few methods have been investigated; but they require too much area in the line of sight, and such space is at a premium.

The gas density and flow velocity are needed for calculating the flow. A gas-density transducer has been tested, but it has a relatively low frequency response and a limited temperature range. The transducer had a driven vibrating beam and measured vibration amplitude with strain gauges.

Flow velocity can now be measured only as a time-of-arrival difference of a distinct feature at two locations. Flow velocity as a function of time at a given point would be a very valuable measurement; a mass flowmeter would also be of great value. The transducer system must be able to operate in relatively high radiation fields, must not require space across the line of sight, must have a wide dynamic range, and must be operable on a pipe ranging from 6 to 50 in. in diameter.

CABLES AND SIGNAL CONDITIONING

Most of the signal-conditioning equipment is commercially available; the only major exceptions are the radiation detectors and the SLIFER and CLIFFER. Where possible, dual constant-current excitation is used with half-bridge transducers. Lead-resistance effects are compensated for, and three-wire rather than four-wire cabling is used. The weight and expense saved by the three-wire system are appreciable when cable lengths of 1500-4000 ft for 20-50 channels are considered. The frequency response of long cables affects the system; different cables are used, depending upon the required data. More often than not, the termination of data-acquisition seems to be the result of cable damage rather than transducer damage.

SUMMARY

The various requirements that have been mentioned seem to add up to a "We'd all like that, but be reasonable" list. Shock sensitivity of the transducers and of the adjacent cable should be $<0.01\%$ full scale per g. Temperature compensation should be over a wider range than is usually available, and high temperature transients should have minimal effects. In summary, transducers that will respond rapidly to a single stimulus are needed. Because of computerized data analysis, transducers need not have a linear response. An interesting alternative is a group of transducers, no one of which measures a single variable, but whose outputs can be automatically processed (in real-time or later) to yield measurements of individual parameters.

Fig. 1a. Radioactivity, temperature, acceleration, and velocity measured on a line-of-sight pipe 260 ft from a detonation. (1a) Radiation level. (1b) Gas temperature. (1c) Pipe acceleration. (1d) Integration of 1c. (The noise spike at zero time on Fig. 1c was not integrated.)

Fig. 1b.

Fig. 1c.

Olsen - Fig. 1c.

Fig. 1d.

Olsen - Fig. 1d.

Fig. 2a. Gas pressure measured at the same location as in Fig. 1 by three piezoresistive transducers from different manufacturers. (2a) 0-5000 psia unit. (2b) Another 0-5000 psia unit. (2c) 0-2500 psia unit.

Olsen - Fig. 2a

Fig. 2b.

Olsen - Fig. 2b.

Fig. 2c.

Olsen - Fig. 2c.

Fig. 3. Records from two gas-pressure transducers at the same location, showing shock sensitivity. No real-gas pressure was observed.

Fig. 4a. Records from two gas-pressure transducers at the same location, showing late-time disagreement. (4a) 0-1000 psia unit. (4b) 0-500 psia unit recorded with 0-333 psia range.

Fig. 4b.

Fig. 5. Condition of a foil gauge element damaged by electromagnetic-pulse energy.

Fig. 6. Output of ionization-chamber radiation detector, showing negative output due to shock sensitivity and abnormally long recovery time.

Fig. 7. Output of 0-10,000 psia blast-pressure transducer, showing full-scale transient due to radiation sensitivity.