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STRAIN SENSITIVITY OF PRESSURE TRANSDUCERS
IN A DYNAMIC ENVIRONMENT

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STRAIN SENSITIVITY OF PRESSURE TRANSDUCERS IN A DYNAMIC ENVIRONMENT*

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ABSTRACT

Strain error in pressure measurements is recognized as a trouble source, but seldom is it the major source of error in measurement. In experiments at the USERDA's Nevada Test Site, it has been necessary to obtain dynamic pressure data from inside pipes which are subject to an initial tensile stress of about one-half yield which changes rapidly to failure in a compressive mode.

Static and dynamic data show that representative pressure transducers are subject to strain error and that the error is not only a function of stress in the mounting, but is also dependent on the rotational position of the transducer (about its own axis) as it is ported into the pipe.

Schemes for decoupling the transducer from the pipe without seriously decreasing the burst capability of the installation have been investigated. A mounting using an annular cut-out around the transducer barrel has been devised which significantly decreases strain error and has little effect on the installation integrity or the response to dynamic gas pressure.

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INTRODUCTION

Measurements of dynamic and static pressure in line-of-sight pipes coupled to nuclear detonations are required to provide data on containment of the radioactive debris, to provide design information for future experiments, and to allow comparison with calculated behavior. Parameters other than pressure are also measured but are not within the scope of this paper. The line-of-sight pipe on which the transducers are mounted is generally the weight-bearing member for most of the experimental hardware. The strain in the pipe changes from tension before detonation to compression as the explosion generated shock-wave passes, and has been found to be the source of considerable error. We will illustrate the type of spurious pressure signals observed and outline an investigation and solution of the problem.

MEASUREMENT DESIGN BACKGROUND

Early in the containment diagnostics program, stock transducers (Figure 1A-1) were modified by removing the restricting aperture between the transducer diaphragm and the measurand. The threaded fitting was removed, and the 1.5-in. o.d. transducer case was threaded, as shown in Figure 1A-2. This considerably improved the response-time of the transducer. The 1.5-in. threaded transducers, Figures 1A-2 and 1B, become known as the "Golden Gate Bolts." As time passed, newer, generally smaller, transducer designs were fitted into the 1.5-in. diameter ports with adapters. In a number of instances, the pressure records obtained were suspect for various reasons. In several cases the output appeared to correlate with accelerometer and velocity-gauge data, but differed from normal shock sensitivity. A program of dynamic and static tests has been pursued to investigate the strain sensitivity of various pressure transducers and mounting adapters, and to formulate means of minimizing spurious data.

DYNAMIC TEST RESULTS

Figure 2 shows the layout of instrumentation on a pipe section used for dynamic studies on two nuclear tests. In each case three pressure transducers and an axial strain-gauge were installed. Table 1 lists the transducer types for each event, and Figures 1B, 1C, and 1E-4 show cross-sections of the transducers and mounting details.

Table 1. Transducer types for two nuclear tests.

Experiment Number 1

<u>Channel</u>	<u>Manufacturer</u>	<u>Model</u>	<u>Range</u>
1 PR B	Kulite	XTMS-1-1500-3000A CV*	0 - 207 Bar
1 PR C	Kulite	XCQM-1-250-1000A CC*	0 - 69 Bar
1 PR E-4	Kulite	HKS-7-375-3000A CV	0 - 207 Bar
1 SG	Micro Measurements	EA-06-250AE-350	

Experiment Number 2

<u>Channel</u>	<u>Manufacturer</u>	<u>Model</u>	<u>Range</u>
2 PR B	Kulite	XTMS-1-1500-3000A CV	0 - 207 Bar
2 PR C	Kulite	XCQM-1-250-1000A CC	0 - 69 Bar
2 PR E-4	Kulite	HKS-7-375-3000A CV	0 - 207 Bar
2 SG	Micro Measurements	EA-06-250AE-350	

*NOTE: CV - Constant voltage four-arm bridge
CC - Dual constant current two-arm bridge

Details from the first test show clearly that some designs are very susceptible to case strain.

Figure 3 shows data plots from channels 1 SG, 1 PR B, 1 PR E-4, and 1 PR C. All plots have the same time base intervals and are meant

to provide a means for reader comparison. The strain-gauge output (Figure 3a) shows a peak compressive strain of $-3190 \mu\epsilon$ (relative to the pre-zero-time level) occurs at 40 milliseconds.

The signal output from channel 1 PR B is in form quite similar to the output of 1 SG. A false peak output of 32 bars was caused by coupling the pipe strain onto the active element of the pressure transducer. This transducer did not have an isolation gap and was screwed directly into the pipe. The residual signal output of .6 bars beyond 500 milliseconds is less than the .8 bars indicated by 1 PR E-4, as discussed below. After the transducer has been affected by high levels of strain, it is difficult to say which data are good and which are not.

Some minor strain effects are indicated by 1 PR E-4. The peak output due to strain was about .6 bars, and the output returned to the base line. The residual output not due to strain, which started at 475 milliseconds, was .8 bars. The strain effects are noticeable between 0 and 250 milliseconds. The strain effects are minor, however, considering the pipe strain present. Installation 1 PR E-4 is screwed into an adapter which has a 1.12-in. deep annular gap to provide strain isolation. The adapter is screwed directly into the pipe as shown in Figure 1E-4.

Data from installation 1 PR C indicates no effects due to pipe strain. The transducer also does not indicate the slight pressure increase that the other transducers indicate. There is no reason to believe this channel did not function (or did function, for that matter).

The Golden Gate Bolt design of 1 PR B is clearly inappropriate wherever significant pipe strain can be expected. The strain isolation technique used on the 1 PR E-4 type of transducer worked, but should be further developed. The XCQM-type transducer and adapter system used as 1 PR C appeared to be quite insensitive to strain.

The second nuclear experiment again shows a definite correlation between pipe-strain-induced signals and transducer-strain isolation. The strain-gauge output trace is shown in part a of Figure 4. A peak compressive strain of $-445 \mu\epsilon$ (relative to the pre-zero-time level) occurs at 57 milliseconds and is followed by another compressive strain of $-438 \mu\epsilon$ at 231 milliseconds.

Part b of Figure 4 is the output trace of the 2 PR B pressure transducer and very nearly follows the trace contours of the strain gauge. This transducer does not have an isolation gap and is screwed directly into the pipe. The output of this transducer indicates a pressure of 52 bars. This trace pulse shape is not too confusing, but the second pulse caused by the second strain is much harder to differentiate from a pressure caused pulse. Without the strain gauge data available to help with the analysis, it would be difficult to say what happened. Time, costs, and necessary data channel requirements preclude the continuous use of strain gauges to validate pressure data, so it is necessary to have the transducer elements isolated from pipe strain.

Figure 4 (part c) is the output trace of 2 PR E-4 which indicates a possible but very slight pipe strain effect of -1.5 bars. The effect is temporary and would not normally interfere with analysis. Because the strain levels measured are much lower than normally incurred, the design will be further tested.

Figure 4 (part d) is the output trace of 2 PR C and indicates no strain effects. The XCOM transducer configuration has been specified in the past; recent transducer purchases, however, have been of the 2 PR E external configuration. Further tests are planned for the 2 PR C type of transducer adapter, although a transducer from a different vendor (Figure 1D-2) will be used to better evaluate the adapter design.

The Golden Gate Bolt-design transducer used on channel 2 PR B is very sensitive to case strain and should not be used where pipe strain is expected. The 2 PR E-4 adapter design may not be adequate to eliminate the effects of high pipe strain, hence, a new isolation concept is planned. It is important that this transducer type be effectively isolated because its use is increasing. The 2 PR C adapter worked well.

Attention will be given to the transducer-adapter installation in future experiments to further evaluate the strain isolation capability of the adapter.

Summarizing, Experiments 1 and 2 clearly point out that the Golden Gate Bolt type of transducer should not be used where pipe strain can be expected. Although magnitude and polarity depend on orientation, the

strain sensitivity is still very highly independent of orientation. Data show its use should be severely restricted.

The XCOM-type transducer and adapter combinations provide the best strain isolation. Further tests of this combination are planned, but there is no reason to expect any adverse results.

The HKMS-type transducer and the isolation gap adapter provide a high level of strain isolation. The case sensitivity levels are acceptable, but further development to reduce the sensitivity is continuing.

A new adapter has been designed which will incorporate the use of the HKMS-type transducer, and will employ a high adapter isolation concept. Figure 1G-1 and 1G-2 are cross section sketches of this new design. Present plans are to squeeze-test the adapter and to field an adapter-transducer combination during the Spring of 1975.

STATIC TESTS

Small-Scale Investigation

Small-scale laboratory tests have been made by placing the 1½-in. threaded adapter (with transducer installed) between two matching drilled and tapped blocks (0.50-in. thick). These blocks were then loaded directly in compression in a 20,000-lb universal test machine. This process yielded several results.

(1) A definite case strain sensitivity in the designs shown in Figure 1B through E was found (design A was no longer available for pipe tests when squeeze testing started).

(2) A direct relationship between case load (stress) or hole deformation and case sensitive transducer output was demonstrated (see Figure 5, parts a and b). Thread clearances affect this measurement.

(3) Transducer rotational orientation relative to the direction of the compressive force was found to effect the response to case loading. Tensile effect would be from Poisson compression of the hole 90° from the principal load axis. (See Figure 6, parts a through e.) It should be

mentioned that "negative pressures" have been seen in nuclear test data corresponding with these small-scale data. Also note that a smaller output accompanied a larger compressive strain. A comparison of 1 PR B and 2 PR B maximum outputs is shown in Figure 6, part a. No doubt this is due to the difference in orientation of the two units, which unfortunately was not recorded.

(4) The effect of radial clearance is shown in Figure 6, part d. Curve 1 shows the outputs with 0.0022-in. radial clearance as on the nuclear experiment. The laboratory apparatus could not distort the adapter sufficiently to cause detectable output, so two pieces of .002-in. thick shim stock were inserted one on each side to help reduce the clearance around the diaphragm as shown in Figure 1D-1, view A-A. Curve 2 shows the output of the unit with 0.0002-in. radial clearance. These data indicate that (a) the 20,000-lb machine is incapable of providing actual pipe loads on the adapter, (b) smaller diaphragms are less susceptible to case sensitivity (smaller hole deflection and stouter adapter), and (c) the 0.404-in. to 0.410-in. i.d. adapter must have deformed in the field experience at least .0044 in. on the diameter and in the laboratory at least .0004 in. on the diameter.

(5) A confirmation of the required amount of isolation as shown in Figure B, part c (compare also Figures 1E-1 through 1E-4).

It should be noted that these tests become more ineffective as the adapters become more rigid and the diaphragms smaller as shown in Figure 6, part b. The small-scale tests indicate where a problem may exist, but they do not provide nearly the force required to test the design to field conditions.

Full-Scale Investigation

Because of the uncertainties involved in small-scale testing and study of underground nuclear experimental data, a full-scale test has been initiated using a universal test machine capable of 3×10^6 -lb tension and compression.

The full-scale test is designed to answer questions on the amount of interdependence of the following design variables for guidance in new

transducer/mounting designs: (1) hole diameter, (2) radial clearance, (3) vertical distance of transducer thread from stressed wall, and (4) internal transducer design.

Other questions to be answered are the following: (1) what are the strain levels that occur around holes of various size at known loads, (2) what is the amount of hole deformation under experimental conditions (during routine pull testing of the pipe, the 1 1/2-12 UNF class 2 threaded holes yield enough to require retapping; the 9/16-UNF-18 class 3 threaded holes do not require rework), and (3) what is the amount of deformation of the adapter at the inner and outer pipe wall when under actual experimental conditions.

It is planned to install the transducer/adapter combinations shown in Figures 1B, 1C, 1D-2, 1E-2, 1E-4, 1F-1, 1F-2, 1G-1 and 1G-2 in standard 9 5/8-in., .545-in. wall API P110 drill casing. These installations will be carefully arranged so that each transducer is oriented with its most strain-sensitive axis parallel with the longitudinal pipe axis.

SUMMARY

In our experience with small and large scale laboratory testing, as well as with actual underground nuclear testing, it has been shown that the best mounting strain decoupling is achieved using the "floating" principal shown in Figures 1C, 1D-1 and 1D-2. The non-threaded transducer is firmly clamped in place in an axis vertical to the planes of any stresses which could be transmitted to its case. Radial clearance must be provided, along with almost total flexibility and sealing in the plane of the major stresses.

It was found that threaded transducers require a deep annular groove (depth greater than two times the mounting thickness as shown in Figure 1E-4). In each of the designs mentioned above, the decoupling adapter is complex, and it is difficult to effect a vacuum seal at the 1/2-in. thread.

The design shown in Figure 1G-1 was provided to overcome the vacuum seal problem, to upgrade the pressure capacity, and to reduce the installation cost. The smaller port design should prove to be adequate to decouple the transducer from mounting strain. Should the design shown in Figure 1G-1 be inadequate, the design in Figure 1G-2 was devised to provide additional decoupling by moving the transducer thread further from the pipe wall. This lengthening must be done with caution, however, to keep from introducing mechanical shock sensitivity and fluid dynamic effects from high flow, fast rise time pressure pulses. If the 1G-2 configuration proves inadequate, use will be made of a combination of the 9/16-in. 1G-1 type pipe port with a non-threaded transducer (such as the configuration shown in Figure 1C and 1B).

Data will be gathered through proper instrumentation of the full scale test specimen, which will help in designing effective small scale tests and ultimately in designing transducer installations for underground nuclear experiments.

The configurations discussed here can be applied to any situation in which a pressure measurement is required under conditions where mounting strains may produce erroneous data.

"Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable."

PRESSURE TRANSDUCER INSTALLATION
FAIRCHILD TF 150-1-0107

A-1

PRESSURE TRANSDUCER INSTALLATION
FAIRCHILD MOD TF 150-1-0126

A-2

PRESSURE TRANSDUCER INSTALLATION
KULITE XTMS-1-1500-3000

B

Figure 1. Pressure transducer installations.

PRESSURE TRANSDUCER INSTALLATION
KULITE XQQM-1-250

C

PRESSURE TRANSDUCER INSTALLATION
ENTRAN EPG-400WA

D-1

PRESSURE TRANSDUCER INSTALLATION
ENTRAN EPG-0400

D-2

Figure 1. Pressure transducer installations (continued).

LB102677-1

E-1

LB102677-2

E-2

LB103241-1

E-3

LB103253-1

E-4

Figure 1. Pressure transducer installations (continued).

PRESSURE TRANSDUCER INSTALLATION
WITH LB-103253-1 ADAPTER
KULITE HKMS-375-3000

E-4

PRESSURE TRANSDUCER INSTALLATION
KULITE HKMS-375
WITH .37 DEEP RELIEF

F-1

PRESSURE TRANSDUCER INSTALLATION
KULITE HKMS-375

F-2

Figure 1. Pressure transducer installations (continued).

PRESSURE TRANSDUCER INSTALLATION
LC 103285-1 CONFIGURATION

G-1

PRESSURE TRANSDUCER INSTALLATION
LC 103351-1 CONFIGURATION

G-2

Figure 1. Pressure transducer installations (continued).

Figure 3. Test data from Nuclear Test No. 1

Figure 4. Test data from Nuclear Test No. 2

a

b

Figure 5. Effect of increasing case load on pressure transducer output.

a

b

Figure 6. Transducer rotational orientation, with respect to the direction of the compressive principal load, effect on output as a response to case loading of 20,000 lb.

Figure 6. Transducer rotational orientation, with respect to the direction of the compressive principal load, effect on output as a response to case loading of 20,000 lb. (continued).