DATA INSURANCE

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We insure our lives, cars, homes, health and a lot of other things. Why not insure our data, harvested with great effort and at great expense? The concept of Data Insurance is based on *CHECK CHANNELS* or *CHECKING PROCEDURES* which are all but neglected these days.

I have attended numerous conferences filled with papers describing tests which cost millions of dollars, occupying hundreds of data channels in sometimes very hostile environments - without any thought being given to checking whether or not the data being recorded represent the process of interest or one of the many environmental factors which were not of interest, and which might even occupy the same time and frequency scales and create effects even larger than those of the data desired. In my lectures I have demonstrated and in my writings referenced numerous case studies of this type. A few will be cited in this article.

Since all transducers respond in all ways in which they can to all environmental stimuli, every measurement system must be assumed guilty of all possible crimes until proven innocent beyond shadow of reasonable doubt.

Such proofs of innocence must come from the measurement system itself and the way in which the test is conducted. They can not be deduced by comparison with any theory. Theories are always in doubt and are supposed to be verified by experiment, not the other way around.

Whether for the measurement of high speed transients, pyroshock, explosions, or for steady state testing such as vibration exciters for modal analysis and observations of operating machinery, or for simple static testing, diagnostic checks are absolutely crucial to data integrity.

Check Channels occupy channel capacity and Checking Procedure take time, both at a premium these days. They also take forethought and planning, but without them there is no way to tell fact from fiction, valid data from garbage.

Bad data look just as believable as good data!

In most checking procedures the effort is to produce a condition where *NO OUTPUT* is expected - if one is obtained it is pure, certified, unadulterated garbage. In the first two-thirds of the 20th Century, testing was cheap and computer operation expensive, so tests could be repeated often under different conditions. As we enter the 21st Century, testing has become very expensive and computer power is readily available at relatively low cost. The few tests which we can afford, *MUST* be above reproach and yield provably valid data.

There is also a class of checking procedures where a condition is produced for which a *KNOWN* output is expected such as Shunt-Span-Verification (used to be called Shunt Calibration) for resistive transducers. But other, highly imaginative applications of this principle have been used. This method will not be discussed here.

In this brief article it is not possible to discuss the entire subject, on which the author has lectured and written extensively - but only to present some basic principles and ideas.

TYPICAL CHECKING PROCEDURES:

In Impedance-Based transducers such as strain-gage-based load cells, pressure transducers, accelerometers, and strain gages themselves, disconnect the interrogating power (bridge) supply and short-circuit (for voltage fed systems) the bridge terminals to which it was applied. ANY voltage output from the transducer under test conditions can NOT be caused by a resistance-strain effect. That voltage may be caused through thermoelectric, electromagnetic, triboelectric, piezoelectric, electrostatic, photovoltaic, ground loop etc. effects; it has even been documented that dynamic-strain-induced voltages exist in thermocouples and strain gage based transducers. (See the first article in this series).

Such voltages can always be eliminated by the use of a well-designed carrier system (see the last article in this series) and/or by appropriate shielding (thermal, magnetic, electrostatic, mechanical, optical, etc.).Such bridge-power-defeat switches may be manual or computer-programmable, but *PROVISION FOR THEM MUST BE MADE*! If bridge power removal creates too much of a thermal shock on the transducer then bridge power polarity reversal is an option. The output should also reverse polarity. It is a sad condition that over 90% of signal conditioning sold for resistive transducers have no provision for such checks!

In pressure measurements where the transducer is connected to the pressure source through tubing, it is always possible to install a valve in that tubing so that the transducer sees no pressure when the valve is closed. (The transducer may be vented to atmosphere during such a check). The transducer and the piping are still in the temperature gradient in which they operated (and the process fluid and the environment are almost always sat different temperatures so that a temperature gradient always exists along the connecting tubing). They still vibrate the same way and other environmental factors have all remained the same. Any out during such a check is garbage. I have seen measurement system outputs *INCREASE* during such a check!

SPECIAL CASES:

In differential pressure measurements, the effect of line pressure (common mode pressure) on the transducer must always be checked. It is possible, by means of pneumatic switching, to connect both input ports of such transducers to line pressure, Ref. 1. *ANY* output is now guaranteed unrelated to differential pressure (since both ports experience the same input). It is necessary, for dynamic pressures, to make the tubing length to both ports the same.)

It is only the imagination of the Measurement Engineer which limits the possibilities for these kinds of checks.

TYPICAL CHECK CHANNELS

There are two basic types of check channels:

1- Those which *DO NOT RESPOND* to the desired environment, but do to the undesired ones.
2- Those which *ARE NOT EXPOSED* to the desired environment, but are exposed to all other environmental factors.

NON-RESPONSIVE TRANSDUCERS:

THE UNPOLARIZED FERROELECTRIC CERAMIC TRANSDUCER:

In order to become piezoelectric, a ferroelectric ceramic must be polarized (or poled) after being fired to assume solid, machinable form. If it remains unpolarized it will not generate charges under mechanical inputs. It occurred to Pierre Fusilier, Head of the Transducer Group at Lawrence Livermore National Laboratories (LLNL) (then Lawrence Radiation Lab) in the very early 1960s, to ask Endevco to produce the same kind of transducers which the Lab was using, but not to polarize them. After considerable persuasion Endevco produced these and has produced them for their customers, on demand, ever since. Endevco is the only manufacturer of which I am aware, who does this regularly, hence the mention of the name. At LLNL they even send such check channel accelerometers to their calibration lab to make sure they don't respond to acceleration.

These check channels do respond to many - but not all - of the other environmental factors which may be present during a test.

THE Z-CUT QUARTZ CRYSTAL:

A Z-cut quartz crystal does not exhibit piezoelectric behavior. The only manufacturer of whom I am aware who makes those is PCB Piezotronics with Ben Granath's expertise. Such check channels have revealed a number of previously unsuspected and illegal contributors to transducer outputs. (Ref.2)

THE 1, 1, 1 CUT p-SILICON CRYSTAL:

Whereas the 1, 0, 0 cut p-Si crystal produces gage factors in the dozens, up to 120, the 1, 0, 0 cut p-Si crystal has an effectively zero (very, very low) gage factor. But both cuts have the same resistance-temperature coefficient and the same nuclear-radiation vs. resistance properties. Such check channels are produced by Endevco and by Kulite, the only two manufacturers of which the author is aware. They have been extensively used, especially in the nuclear industry.

THE FOUR-TERMINAL THERMOCOUPLE

Thermocouples made of *TWO* legs each of Material A and Material B, such as Chromel-P/Alumel, now become four-terminal thermocouples. During the test the A-A and the B-B connections are checked. ANY output from those alert the experimenter to connector problems, EMI, RFI, ground loops and a whole family of problems to which thermocouples are heir. Dr. Ray Reed of Sandia National Labs (now retired) has used such checks extensively to document the validity of his thermocouple channels. (Ref. 1)

CHANNELS NOT EXPOSED TO THE DESIRED ENVIRONMENT

Just a few examples: A strain gage of the same Lot No. as the measuring gage is mounted on a coupon of the same material as the test specimen and in the same direction as the measuring gage. The coupon is attached to the test specimen in such a manner that the coupon is not strained (i.e. at one point). It is then in the same environment as the measuring gage but not under strain - this is also known as a <dummy> gage, although it is the smartest member of the test apparatus.

A pressure transducer mounted in a blind hole but which is vented to atmosphere, right next to the measuring transducer which goes into the pipe. Both are under similar environments but only one is subjected to pressure. (See Case Study No. 9 and Ref. 7)

An accelerometer suspended from rubber bands, hand-held near each measuring accelerometer on a specimen on an electromagnetically excited vibration table. Dominic 'Dick' DeMichele, founder of the International Modal Analysis Conferences (IMAC) relates this practice from his 40 years as Head, Instrumentation Development at General Electric Co. Schenectady, NY.

Again, only the imagination of the Measurement Engineer limits the application of these principles.

A FEW CASE STUDIES

The author was involved directly or indirectly in the case studies

1. A shock separation test, (Refs. 2, 3), Feb. 25, 1990, organized by TRW Space & Technology at McDonnell-Douglas, Huntington Beach, CA. 10,000g-peak to test gage survival, Dynamics 7600 A signal conditioning, 5v and0v supply for Measuring and parallel side-by-side Check Channels. Measuring channel: 1200 micro-strain max; check channel, unpowered, 200 micro-strain signal equivalent max. Strain-induced voltages correlated with signal, to the same time scale and frequency range, never to be separated by the common techniques such as frequency selective filtering, time-domain techniques or statistical or correlation methods.

2. Lawrence Livermore Lab test at Sandia National Labs, Jan. 22, 1987, (Refs. 2, 3) in the 520 ft (150m) long, 19 ft (5.8m) diameter large blast/shock tube. Measuring gages: 13,000 micro-strain max; parallel and side-by-side check channel, unpowered, 1300 micro-strain signal equivalent, see note for Case Study 1.

3. Sandia National Lab, Albuquerque, Rodney May, (Ref. 2). The large Shock Tube was being reinforced for higher blast capacity along with the Minuteman program. A one-quarter of full scale charge was set off. The strain gages indicated 75% of yield-point strains. No check channels were used. Test was repeated with two check channels: one not responding to the measurand and one not powered. 80% of the measurement was noise, i.e. 15%of yield point was the real strain for the quarter-charge!

4. Lawrence Livermore Labs, about 1992, William M. "Bill" Shay, Refs. 2, 4). Quarter-scale test on 1.5 ft thick reinforced concrete room to contain blast effects on explosions. Pacific Instruments Model 8255 signal conditioning. Gages with 12 v bridge supply and with 9 millivolts (lowest possible for that signal conditioning) bridge supply showed exactly the same voltage-time response. ALL the signal was noise! Impromptu shielding and grounding improvement gave 21,000 psi signals and 1600 signal equivalent psi for the measuring and check channels. Later, more thorough magnetic an electrical noise suppression techniques (twisted leads, shielding, etc.) gave a check channel with zero output.

5. Lawrence Livermore Labs, about 1992, William M. "Bill" Shay, (Refs. 2,4). In tests on the Gamma Ray Camera tested in an old 16-inch diameter navy gun to obtain acceleration survivability data. Endevco 7250AM1-10 Piezite polarized ferroelectric ceramic accelerometers used as measuring channels; 7250AM-1-10NM UNPOLARIZED Piezite accelerometer used for check channel. 38g maximum acceleration on the measuring channel was accompanied by no output from the check channel.

6. Motorola Government Electronics Group, Scottsdale, AZ, Keith Kingston, 1992 (Ref. 2,6). Small RF connector being tested for vibration performance which degraded rapidly when shaker was operated, even though the connector had worked properly in practical applications. The output signal was the same when the connector was mechanically connected to the shake table and when it was hand-held close but mechanically disconnected. (No Measurand input). Fringe magnetic fields from the shaker were found to be the cause.

7. Pratt & Whitney JT3D Engine Gear Box, redesigned to transmit more power, (Ref. 3). 29-tooth idler gear failed prematurely. Measurements with DC-fed strain gages on the gear showed 65,000 psi (448 MPa) stresses at two apparent resonant frequencies close to 50 kHz at 12,400 rpm. Data were given to theoretical group who spent frantic, expensive and fruitless days on information which was pure, total, certified and unadulterated garbage. Noise diagnostics with zero-volt gage supply showed 37,000 psi (255 MPa) with gage excitation on and 42,700 psi (294 MPa) with gage excitation off, with both channels showing the same frequency content and amplitude traces. From the data so gathered a sine-wave carrier system was designed, of 500,000 Hz frequency 10 volt supply and a filter to remove the voltage-noise which was larger than the signal plus the noise (!). Results showed a giant once-per-revolution impact of 50,000 psi (345 MPa) with no resonance in sight. Now that the problem had been diagnosed, the fix was obvious. Carrier systems are remarkably efficient at suppressing ALL voltage noise levels regardless of source, whether understood or not, from ALL impedance changes.

8. Lockheed Missiles & Space Co., Sunnyvale, CA, 1962, (Ref. 5). A tine-shaped part in the actuator chain in the exhaust of a Polaris missile firing was instrumented to measure the transmitted forces. Strain gages were placed only in mutual perpendicular pairs located as stacked-T-rosettes on both sides of both legs of the tine. With mutually perpendicular gages in adjacent bridge arms, the strains will add and any temperature-induced resistance changes will subtract. All internal bridge lead wires were exactly the same length so no output from lead wires was possible. When tested in an oven, the "load cell" showed unacceptably large outputs. But the output were about the same whether bridge supply was ON or OFF, showing that the major portion of the output was a voltage, not a strain. They had completely forgotten the 16 copper-Constantan thermocouples in the 8-gage bridge! The use of a CEC System "D" 20 kHz carrier suppressed these voltage giving less than 5 micro-strain zero shift through the full temperature range of the test.

A note about the new International definitions of Thermal Zero Output. The definition is, unfortunately, nonsense. The output voltage due to temperature from a strain gage transducer will include the thermoelectric voltages when the bridge is fed with DC and exclude them if the bridge is fed from a sine-wave carrier. The recognition that the *ENTIRE TRANSDUCERAND ITS BOUNDARY CONDITIONS MUST BE SPECIFIED COMPLETELY* before a definition can be written, did not occur to the definition writers! – they had no conceptual model of how a transducer works. The Unified Approach to the Engineering of Measurement Systems for Test & Evaluation provides such a conceptual model.

9. Ai Research Manufacturing Co., now AlliedSignal Engines, 1959, Ref. 7. The pressure-time history between blades as viewed from a fixed point on the impeller shroud of a shrouded gas turbine compressor, was to be obtained as the impeller blades passed that point. Blade spacing was 1", the 17-bladed wheel rotated at 47,000 rpm maximum, (13,300 blades/sec passing the pressure-transducer) reaching 350°F operating temperature and having to survive 500°F on soak-back. Maximum pressure was expected to be15 psi. It was desired that the Frequency response of the transducers exceed 10 times the fundamental 11,900 Hz and diameter be less than 1/10the 1" wavelength in order to show 10 harmonics of the fundamental repetition rate. Pressure transducers were mounted in pairs, one in a blind hole vented to atmosphere, right next to the measuring channel. Compressor shroud vibrations and thermal effects were thus monitored. Calibration through the check-channel vent-hole during the test, was possible with the Swiss Locomotive Works (later Kistler) SLM PZ-6 quarts crystal very-low-frequency-response transducers. Of the 100 points on the compressor map, 85 proved uncontaminated - the check-channel output was close to zero. Two points showed major signal contamination, probably from vibration-induced outputs.

CONCLUSION

All data experimentally acquired must be able to pass this acid test: A *YES* answer to the question:

Could *THESE* data have been acquired by *THAT* measurement system without distortion, contamination and without affecting the process being observed- an can you *PROVE* it beyond shadow of reasonable doubt, Check channels provide one of the means for answering this question - *YES*! and the Unified Approach to the Engineering of Measurement Systems provides the rest.

The answer to the question: "But where are your check channels?" is often answered by: "We don't waste our channel capacity and budget on channels which record nothing. We only collect real data!" The results of such tests may be good candidates for the wastebasket.

In the 21st Century we can not afford to waste either time or budget on data which have not been validated by check channels or procedures. It *IS* possible to harvest provably valid data, the first time around - to achieve Success Through Engineered InstrumentatioN!

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