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LOFT TWO-PHASE FLOW DATA INTEGRITY ANALYSIS

L. D. Goodrich
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, Idaho 83401

L. P. Leach
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, Idaho 83401

ABSTRACT

Data integrity methods have been developed and applied to Loss-Of-Fluid Test (LOFT) nuclear reactor safety experiments at the Idaho National Engineering Laboratory. The methods for improving and qualifying the accuracy of transient measurements on complex thermal-hydraulic experiments are described. These methods involve use of all the information available on the transducers, including data taken during the LOFT experiment itself. Optimum use of these methods determine, in part, the instrumentation package provided on the experiment.

INTRODUCTION

In the past, an experimentor was able to make significant contributions in the scientific field with relatively simple instrumentation, such as thermometers and manometers. As the complexity of the experiments increased, miles of strip charts would be reduced following an experiment by many individuals with rulers and, perhaps, calculators. The experimentor, in those days, understood both the experiment and measurement system and thus could guarantee data integrity, i.e., high quality data. Much more sophisticated and complex measurement systems recording over 1 000 transient parameters are sometimes required to meet the needs of experimentors today. The complexity of the measurement systems and sheer mass of data requires a controlled multidisciplined approach to evaluate and optimize the information. A data integrity program was developed for the LOFT Program to guarantee a high level of data quality. The following is a discussion of this program.

PRETEST

Pretest data integrity functions guarantee that the necessary documentation and procedures are available to check transducer outputs for drifts in zero offset and the calibraton coefficient. The pretest data integrity functions are: (a) laboratory calibration, (b) transducer performance characterization, and (c) in-situ calibration checks.

LABORATORY CALIBRATION

Guaranteeing data integrity begins with a laboratory calibration that is traceable to the National Bureau of Standards. This calibration serves as the reference for the slope coefficient D_1 in the linear equation:

$$M = D_0 + D_1 E$$

where:

M = measurand

D_0 = zero offset

D_1 = slope coefficient

E = voltage output of transducer.

Thorough documentation of the calibration is maintained at all times.

PERFORMANCE CHARACTERIZATION

If the transducer is calibrated under one set of conditions and then to be used under a different set (for example, calibrated in water but applied in a steam-water environment), performance characterization tests must be performed. The laboratory calibration is normally more accurate than a calibration in the intended steam-water environment; therefore, the performance characterization must be designed to establish a correlation between the laboratory calibration and the intended use.

In addition to the calibration characterization, the installation effects must be quantified if possible. This qualification accounts for geometry effects (especially swirl, etc., for flow devices) and both the system and any transducer mounting devices used that were not part of the calibration fixtures. Transducer uncertainties, using the performance characterization, are quantified under this function.

IN-SITU CALIBRATION CHECKS

The next step in guaranteeing data integrity is to perform in-situ calibraton checks following

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installation of the transducer in the system. These checks should be performed prior to each test series and are to (a) verify that the calibration or slope coefficient has not statistically changed and (b) establish the zero offset. The statistical tool for verifying changes is the t-test.

The equation for the t-test is:

if $t \geq \frac{D_1 - D_{ref}}{S_1}$ the coefficient has not changed

where:

- t = student's T value for the sample size
- D_1 = calibration slope from the in-situ calibration
- D_{ref} = calibration coefficient from laboratory calibration
- S_1 = variance of D_1.

If this test fails then a problem, such as shifts in excitation voltage, signal conditioning, or a drift problem with the transducer, is indicated.

The type of tests used for in-situ calibration checks are:

* Isothermal Checks -- Isothermal checks are made by making cross checks of fluid and metal structural temperature measurements obtained from thermocouples against those obtained from resistance thermometer detectors at several temperature plateaus encompassing the range of experiment operation. A probability density function can be used to easily and quickly identify errant channels.

* Static Checks -- Static pressure checks consist of cross checks of experimental pressure and differential pressure transducer measurements against reference pressure transducer measurements. These checks are made at several pressure plateaus at each of the temperature plateaus. Data from experimental transducers are compared with those from reference transducers to ascertain whether the slope coefficients have changed. The t-test described previously is used as the analysis tool. In-place calibrations can be used in place of this check.

* Steady State Checks -- Steady state checks consist of calibrations of experimental velocity and fluid momentum transducers against calibrated venturi or orifice flowmeters, or both. These checks not only check calibration but can check some basic performance characteristics, such as geometry effects. Loop closure, using differential pressure, is also checked using steady state tests.

* Flow Coastdown Checks -- Some transducers are overranged during steady state operation because they are designed for optimum performance during the transient. In LOFT, outputs in the range of the transducer may not be achievable during steady state operation. To check these transducers, flow coastdown checks are made.

TEST FUNCTIONS

Just prior to the initiation of the experiment, voltage insertion calibratons are performed on all measurement channels. A burst of steady state data is taken and subjected to the steady state data analysis techniques. Additional checks for extremely high standard deviations for initial and final conditions and checks of the transient for discontinuities and excessive noise are made. Analysis of these data primarily indicates shifts in the zero offset term. Following the transient test, the voltage insertion calibration and steady state data review are repeated.

POSTTEST INTEGRITY ANALYSIS

The purpose of posttest data integrity analysis is twofold. The first purpose is to determine how well the transducers performed and inform users how much they should rely on the experimental data. LOFT data are "qualified" into four categories as a result of this process:

* Qualified Engineering Units Data (QEUD) -- Data that have been verified to be within the specified accuracy by independent cross checks.

* Restrained Data -- Data that could not be QEUD over the whole range because of special restrictions that accompany the data. An example is a low range pressure transducer which would be "restrained" during the portion of the experiment where measured pressure exceeds transducer range.

* Trend Data -- Data which are believed to be accurate within specified accuracy, but for which no independent check was possible.

* Failed Data -- The measurement system failed, for example, either the transducer, data acquisition channel, signal conditioning, or cabling failed.

Table I presents a sample of the results of this qualification process for the LOFT experiments. This information can now be used to implement improvements in the measurement system by highlighting the measurements with high failure rate or areas in which additional information is required (special tests, additional instruments, or additional analysis techniques) to make the data qualifiable.

The second purpose of the posttest data integrity analysis is to actually improve the quality and accuracy of the data. The first instance of making this improvement is application of the measurement "cross sensitivities," derived from instrument calibration. Additional improvements in the accuracy and reliability of the data result from the posttest integrity analysis. Specific analyses performed are as follows:

* Thermodynamic equilibrium between measured fluid pressure and temperature during portions of the transient where two phases (steam and water) exist.

* Mass balances in injected emergency core coolant, flow of fluid from the LOFT system, and accumulation of fluid in the LOFT blowdown suppression tank.

* Calculation of transient two-phase mass flows in the LOFT system by five different methods, and comparison wit' the integral mass flow obtained in the second item.

* Transient pressure differential closure calculations (that is, $\Sigma \Delta P's = 0$).

* Further in-situ cross calibration of two-phase mass flow measurement devices during the first second of the transient when flow is still single-phase.

* End point checks including comparing the "end point" of wide range pressure transducer data with low range pressure transducers, fluid momentum flux measurements to a zero flow condition, and fluid density to an all water or all steam conditions.

* Consistency checks to determine whether: (a) the drag disc indicates high ρv^2 when the densitometer indicates high density and (b) the data compare with previous test performed under similar conditions.

Completion of this process highlights the areas where instruments are in error and places where additional measurements are required to qualify the data. For example, the need to provide reference pressure measurements to facilitate the pretransient data integrity analysis was noted on LOFT. Additional differential pressure measurements were added to complete "loops" and facilitate pressure drop closure calculations. Several measurement system problems, such as inadequate reference leg filling of level measurement transducers and temperature sensitivity of drag-disc turbine transducers, have been made apparent by this process, which has led to modification of these measurement systems.

CONCLUSIONS

A procedure for reviewing and assigning qualification levels to each measurement in LOFT has been established. This program has impacted instrument location and quantities. Besides allowing certification of accuracy, this data integrity program allowed identification and correction of instrument problems.

TABLE I

SAMPLE SUMMARY OF POSTTEST INTEGRITY ANALYSIS

Instrument Type	Total Installed	Number QEUD	Number Trend	Number Restrained	Number Failed	Number Not Reviewed
Accelerometer	33	24	0	2	5	2
Densitometer	12	9	0	0	3	0
Displacement	2	2	0	0	0	0
Liquid level	17	7	9	0	1	0
Momentum flux	17	3	9	3	2	0
Differential pressure	34	12	7	8	6	1
Absolute pressure	59	29	6	14	9	1
Pump speed	2	1	0	0	1	0
Thermocouples	353	291	12	11	23	16
Totals	529	378	43	38	50	20