“Nightmares of the Art of Measuring”

Compiled and Edited by G. Hathaway
Toronto, Canada
Feb 2006

The title of this compendium is taken from Rudolf Zinsser’s tract on his Kinetobaric Effect discovery. It refers to the problems and pitfalls that experimental physicists run into during the course of investigation into anomalous forces, including gravitational forces. It is hoped this compendium will be continually updated and augmented as time goes on by those who have experienced one or more of the situations listed below.

I have tried to organize the list into more-or-less distinct categories but there will inevitably be some overlap. Electronic versions of this list will, no doubt, allow easier searching for information on specific concerns.

I want to recognize those who have contributed to the compendium, so I will be including a list of names at the end. It is hoped that some or all of these contributors will allow others to contact them in order to assist in sorting out particular situations.

I **MECHANICAL EFFECTS**

A. THERMAL EFFECTS

1. Thermally-driven convective air or gas movements causing test masses connected to balances to move. Also results from condensation of water vapour onto test mass or suspension during cryogenic experiments.
2. Radiometer effects on a test mass (in a radiometer, blade movement is caused by pressure of thin gas layers near blades due to absorption of solar energy).
3. Change of heat transfer conditions between test mass surface and liquid. This depends on i) delta-T between them which can change substantially over time, ii) thermal diffusivity of test mass.
4. Thermally-driven convective movement in liquid (usually cryogens) causing weight artifacts in submerged test masses connected to balances.
5. Change in length of lever arms or period of torsion balance due to thermal contraction/expansion.
6. Change in response of balances due to differential thermal expansion coefficients.
7. Short- or long-term temperature-induced drift of electronics in recording devices/amplifiers/signal conditioners.
8. Thermal noise in balance structures, eg, torsion fibre and masses in a Cavendish balance.
9. Thermal gradients, and their time excursions, induced in test masses, especially superconductors (with corresponding distributions of superconducting or non-superconducting phases), resulting in only partial conditioning (eg only part of the superconductor is in superconducting state) due to insufficient or inefficient cool-down or warm-up. Effect exacerbated by non-uniform test mass composition, density and thermal diffusivity.

10. Altered buoyancy of test masses, especially superconductors, in liquids (usually cryogens) due to free convection or 2-phase flow (gas bubble/liquid) in thin liquid layers close to the mass surface causing variations in liquid/solid friction.

B. BUOYANCY EFFECTS

1. Different-shaped test, counterweight and dummy masses exhibit different buoyancy effects even in low-pressure gas.
2. Expected or calculated buoyancy of test mass or counterweight mass is enhanced or decreased by horizontal thermal stratification of still gas/air.
3. Account for buoyancy differences due to temperature differences even in low pressure gas.
4. Thermal shrinkage of test masses and supporting structures during cool-down causing reduction of buoyancy, eg in sample holders with large thermal expansion coefficients.
5. Absorbtion of water vapour, oxygen or other gasses from the air by and into the cryogen causing density variations and corresponding variations in buoyancy.
6. Thermal expansion during warm-up of test mass causing increase in buoyancy in gas or liquid.

C. SEISMIC/VIBRATION EFFECTS

1. Local seismic noise effecting one part of a balance preferentially.
2. Subtle seismic or structural vibrations serendipitously synchronized to the expected experimental effect being measured interpreted as signal of real effect. This is especially true for condenser and other sensitive microphones due to high sensitivity over wide frequency response, which are clamped to a laboratory structure.
3. Vibrations from local rotating machines, eg roughing and turbomechanical pumps.

D. DIURNAL & RELATED GRAVITATIONAL EFFECTS

1. Effect of motion of moon on sensitive balances.
2. Tidal motions of earth's crust altering orientation or periodicity of observations.
3. Cautions regarding use of sealed gravitometers for force detection (placement with respect to experiment, size of internal detection mass, handling, temperature, etc)
4. Avoidance of moving masses in laboratory (eg people and equipment) during sensitive gravity experiments.

E. VACUUM EFFECTS

1. Outgassing of materials in vacuum interacting with movable masses.
2. Outgassing of fastening/joining methods, eg blind bold holes interacting with movable masses.
3. Mechanical strains on structural/electrical/measuring components during pump-down.
4. Slow leaks resulting in air stream impacting test mass.

F. CORIOLIS/EARTH ROTATION, TORQUES

1. Correction for Coriolis "acceleration"/earth rotation effects in extremely sensitive moving-mass force-detection systems.
2. For test masses firmly fixed to a balance arm without provision for pivoting or gimballing, the mass can exert a torque on the arm masquerading as a weight change. Especially true if mass

has a magnetic moment (conductor or non-conductor, magnetic or non-magnetic) either induced or permanent, then stray fields can induce a “magnetic” torque in the test mass.
3. Balance arm lengthening due to extended test mass firmly fixed to balance arm.

G. LIQUID EFFECTS

1. Noise induced in weight/force measuring instruments due to separation of tests mass from liquid (usually cryogen) bath while lifting mass out of bath.
2. Noise induced in weight/force measuring instruments due to evaporation of liquid (usually cryogen) from surface of test mass.
3. Weight artifacts induced in suspended test masses approaching cryogenic temperatures due to condensation of residual water vapour on test mass and suspension not removed by vacuum system. This effect can appear as an increasing weight over time as more water vapour condenses.
4. Artifactual and fluctuating weight changes due to de-wetting of suspension (usually wire or filament) of submerged test mass while surrounding liquid evaporates and level decreases. This effect increases with surface tension, test mass circumference, and decreases with increasing contact angle. Surface roughness also important.
5. Surface tension can exert undesirable forces on a test mass when it passes through the surface of a liquid.

II **TEMPORAL EFFECTS**

A. SIGNAL DURATION EFFECTS

1. Mismatch between time scale/time constants of measuring device vs experimental variable.
2. Long-duration signals lost in long-term natural drift of experimental parameters.

B. TEST MASS CONDITIONING

1. Allowance of sufficient time for sample to reach required temperature (eg cooling a superconductor to below transition temperature) between measurements if direct temperature determination is difficult or impossible.

III **ELECTROMAGNETIC EFFECTS**

A. MAGNETIC COUPLING

1. Influence of time-varying fields on non-magnetic but conducting bodies inducing local magnetic fields in conducting bodies which may be attracted or repelled from the field or other nearby bodies.
2. Simple magnetic coupling between magnetizable bodies considered unmagnetized before the experiment.
3. Over-reliance on magnetic shielding material which needs special handling and re-annealing after machining/forming/bending etc.

4. Improper reliance on magnetic shielding material for exclusion of DC or quasi-static magnetic fields.
5. Influence of earth's static magnetic field, gradient and dip on magnetic bodies.
6. Stray artificial magnetic fields causing spurious electron beam deflection on oscilloscopes.
7. Sudden release of trapped magnetic fields in superconductors raised above transition temperature affecting & affected by nearby magnetic or conductive structures.
8. Coupling between magnetic moment of superconducting test mass and external magnetic fields including earth's field.

B. ELECTRIC COUPLING

1. Leaking/improperly sealed Faraday Cage/electrostatic screens.
2. Improper reliance on Faraday Cage for complete exclusion of DC or quasi-static electric fields.

C. ELECTROMAGNETIC COUPLING

1. "Lorentz-Air" effect being the coupling of time varying EM fields in air on the local air molecules. (J. Woodward to check)
2. Avoidance of switching transients especially in high-power circuits, especially sudden stopping of current though inductive loads or conductors producing EMP inducing large spurious signals even through shielded coax or aluminum instrument boxes/cases.
3. High frequency RF radiation from nearby transmission lines or conductors interfering with electronic weigh scales.
4. Lack of RF suppression on instrument power lines and instrument lines, eg ferrites, shunting caps, proper RF connectors & cables, unless disallowed for frequency response reasons.
5. Avoidance of capacitive coupling between signal cables and grounds/ground leads carrying transient/fault currents.
6. When a source is incorrectly matched to a load, a greatly increased level of EMI across a broad frequency range may be generated as the reflected power interferes with the correct operation of the source (an amplifier usually). This in turn may cause spurious measurements to occur, and this is particularly troublesome when using an electronic balance.
7. Casimir force between test mass and measuring system at nano-scale dimensions.

D. GROUNDING/EARTHING PROBLEMS

1. Avoidance of contact potentials developing across multiple ground connections. In some cases contact potentials must be compensated by a deliberately applied counter potential.
2. Strive for single-point RF ground system for all instruments.
3. Correction of ground loops and ground faults both internal to the experiment and between experiment and measuring system.
4. Poor/loose ground connections: preventing complete charge draining, allow transient voltage artifacts on recording & display devices, allow small signals to be amplified by amplifiers along with the signal of interest, etc.

IV **ELECTROSTATIC AND RELATED EFFECTS**

A. GRADIENT EFFECTS

1. Gradient of electrostatic field caused induced motion in nearby free bodies.

B. CHARGE POOLING AND INDUCED CHARGES

1. Accumulation of pools of surface charges on invisible insulating patches on conductors. Especially problematic for metal enclosures/surfaces which have unavoidable insulating metal oxide layer formed on surface, eg aluminum.
2. Accumulation of charge on insulating or non-conductive surfaces, eg wire insulation, after exposure to electrostatic and sometimes time-varying electric fields.
3. Reaction against image charges created on conductors.

C. ION AND MOLECULAR EFFECTS

1. "Ion wind" due to ionized surrounding gas causing artificial force on conductors especially in high-voltage DC or AC experiments.
2. High-voltage ablation/sputtering of molecules or ions from conductors or insulators.

D. CHARGE LEAKAGE

1. Unaccounted-for corona or other uncontrolled charge leakage usually in bursts ("Tricel Pulses") in high-voltage experiments which can create time-varying charge on nearby conductors. Especially problematic at sharp corners.
2. Ions from leakage current interacting with gas molecules and imparting thrust to the leakage ion source body.
3. High voltage creation of weak conduction paths between device under test and ground. Depends on humidity, vacuum.

V **SIGNAL ANALYSIS**

A. AVERAGING (to tease out buried signals and suppress noise)
B. STATISTICAL ANALYSIS (use of Chi^2, calc. of correlation coefficients, sigmas, etc)
C. NOISE (is noise floor burying signals of interest)
D. ERROR ANALYSIS (how confident that signal is inside measuring instrument range and is real – requires full specs. of instrumentation, error propagation)
E. EXPLOITING ADJUSTABLE PARAMETERS

1. Adjusting phase of various parameters to detect artifacts
2. Suppression of common-mode noise.
3. Alternate mechanical orientation of experiment with respect to possible local forces or gravity.

VI **TEST MASS PROPERTIES, USE OF PLACEBO/DUMMY TEST MASS**

1. Replacement of test mass by known null-effect mass.
2. Use of null-effect dummy mass of identical thermal characteristics to test mass, especially in superconductor/cryogen experiments.
3. Reversing sense of one experimental variable to determine if observed effect goes away.
4. Shorting one component or use of dummy electrical component with same electrical characteristics.
5. When using superconductors as test mass, check for correlations with test mass being in Meissner state.
6. Investigate all properties of test mass before and after experiment, including volume properties (phases, crystal or amorphous structure, chemical composition, absorbed species, density, thermal diffusivity) and surface properties (morphology, interfacial energy, wettability, depositions/adsorption, corrosion and erosion).

VII **INSTRUMENTATION ISSUES**

1. Measurement outside specifications of instruments including sensing/measuring instruments, signal processors/amplifiers/conditioners, and recording/display/acquisition devices.
2. Lock-in amplifier response to high-amplitude transients riding on input lines causing artifacts even when not phase locked to the reference signal.
3. Voltage sags/surges resulting in poor mains power quality, eg startup of nearby large rotating equipment.
4. Ensuring correct vertical/plumb orientation of torsion balances especially while on anti-vibration tables.

Acknowledgements

I am indebted to the following persons who have assisted in assembling the list above:

Rudolf Zinsser, Germany (deceased)
Harald Reiss, U. of Wuerzburg, Germany
Scott Little, Institute for Advanced Studies, Austin
Bruce Towe, Arizona State U.
Jim Woodward, Cal. State U. at Fullerton
Paul March, Friendswood, TX
F.X. Canning, C. Melcher, E. Winet, Institute for Scientific Research, WV
Andrew Palfreyman, San Jose, CA

plus anonymous contributors.

Version 1.0