Normal Force PLATES

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Multi-axis Force Transducer Calibration Report

Note: The first 4 pages of this report contain general information applicable to any unit. The last 2 pages contain information specific to this unit.

GENERAL USE

Sensitivity
A 6-component transducer will measure the 3 force components (Fx, Fy, Fz) and 3 moment components (Mx, My, Mz) which act on the dynamometer. To operate, each channel must have an input voltage Vo applied (typically 5 - 10 volts). For each of the 6 input components (force, moment) there is then a corresponding output voltage. The ratio of output to input is defined as the "Sensitivity" for each channel, where output is the dimensionless quantity uV/Vo (micro-volts out/input voltage) and input is the corresponding force or moment.

Example
The channel sensitivity S is used to compute the output voltage for each channel according to the following equation:

Output voltage = .000001 * S * Vo * G * Input

Where: Output voltage is the output from the amplifier used
S is the channel sensitivity as defined above
Vo is the channel input voltage
G = amplifier gain (volts/volt)
Input is the applied force or moment
.000001 is simply volts/micro-volt

As an example, consider the following:
Fz sensitivity S = 0.1 uV/V/N (micro-volts per volt per Newton)
Vo = 10 volts
G = 4000
Fz = 800 Newtons

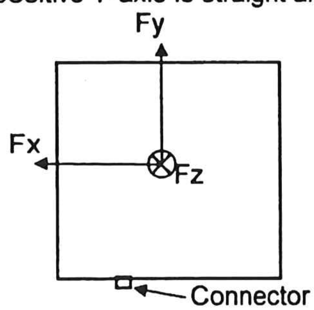
Then output = .000001 * .1 * 10 * 4000 * 800 = 3.2 volts

Continuing this example, assume that this unit is connected to an A/D converter that converts the analog output voltage to a number of bits which can be read by a computer:
A typical A/D converter would be a "12 bit converter" with +/- 10 volts full scale input. This translates to 2^12 = 4096 bits for an input range of 20 volts; or 204.8 bits/volt. Thus 800 Newtons would give 204.8 * 3.2 = 655 bits.

Conversely, if for this example we should measure an A/D board output of 600 bits, this would correspond to an input force of Fz = (600/655)*800 = 732.8 N

Coordinate System

The forces and moments are measured relative to a standard XYZ system of coordinates. The origin of the XYZ system is at the point where an application of Fx, Fy, or Fz will (theoretically) produce zero moment output. (Sometimes termed the shear center of the unit.) This point is normally inside the transducer.
For most transducers, in their usual operating position, the positive X-axis is to the left; the positive Y-axis is straight ahead; and the positive Z-axis is downward. (AMTI convention)



XYZ system is located
zo below the top.
xo to the left
yo upward as shown

Note: xo and yo are normally
very small and can be neglected

View of Top Surface

In operation, the user will normally want to know the forces and moments relative to a different, user, xyz coordinate system, parallel to XYZ, but having a different origin, often at the top surface of the unit. During calibration we determine the location of the origin of the XYZ system (shear center) relative to the xyz system located at the geometric center of the top surface of the unit. This location is given by xo, yo, and zo. Again, xo, yo, and zo give the location of the shear center relative to the geometric center of the top surface.

Moments

The forces measured, Fx, Fy, and Fz, do not depend on the location of the origin of the user coordinate system. However, the moments Mx, My, and Mz do. Suppose we should want to determine the moments about, user x, y, z axes, with origin at the center of the top surface, as discussed above. The moment readings (which are about the shear center) must be adjusted to account for any moments produced by any forces Fx, Fy, and Fz, which do not act through the shear center. If Mxo, Myo, and Mzo are the moments indicated by the unit, then the true moments about the xyz axes are:

$$Mx = Mxo - Fy*zo - Fz*yo$$
$$My = Myo + Fx*zo + Fz*xo$$
$$Mz = Mzo - Fx*yo - Fy*xo$$

Under most conditions xo and yo are so small that these equations become:

$$Mx = Mxo - Fy*zo$$
$$My = Myo + Fx*zo$$

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Matrix Sensitivity Analysis

When a transducer is calibrated, all 6 outputs are measured for each calibration load applied. Ideally, when, for instance, a force Fz is applied, the only output should be on the Fz channel. However, realistically, there usually will be very small outputs on the other channels also. These outputs represent "cross-talk" between channels and are usually negligible with AMTI force platforms.

In this section we discuss the use of all 6 voltage outputs when computing any of the 6 inputs. Theoretically, these methods should give "better" measurement accuracy. However, due to small nonlinearities and “noise” in the measurement of these already small components, we find that the improvement, if any, is small. This would not be the case with a multiaxis transducer with inherently high crosstalk. For instance, a 20% Fz to Fx crosstalk effect could be reduced to perhaps 3% by the method which will be described. An AMTI force transducer with typically less than ½% Fz to Fx crosstalk over its whole working surface would probably not show significant improvement over its already low value.

As part of the calibration analysis we determine the "best" linear relationship between all 6 inputs and all 6 outputs, and we call this relationship the "sensitivity matrix," a 6x6 matrix, S(i,j). As in the simpler case (above) sensitivity is defined as output/input. Here, however, we now have 6 inputs and for each input, 6 outputs. Using matrix terminology we will let the input be represented by the 6 element force vector Fj, and the output by the 6 element vector Vi.

The 6 elements of Fj are: F1 = Fx, F2 = Fy, F3 = Fz, F4 = Mx, etc.

The 6 elements of Vi are: V1 = VFx/Vo, V2 = VFy/Vo, V3 = VFz/Vo, V4 = VMx/Vo, etc.

Then S(i,j) = Vi / Fj

Note: Here we will reserve the subscript j for the input quantities, which in this instance are the forces, (arranged across the top of the matrix), and I for output quantities (arranged vertically)

		Fx	Fy	Fz	Mx	My	Mz
	j =	1	2	3	4	5	6
VFx	i = 1	S11	S12	S13	S14	S15	S16
VFy	2	S21	S22	S23	S24	S25	S26
VFz	3	S31	S32	S33	S34	S35	S36
VMx	4	S41	S42	S43	S44	S45	S46
VMy	5	S51	S52	S53	S54	S55	S56
VMz	6	S61	S62	S63	S64	S65	S66

The user is not really interested in computing the voltages due to a set of forces. Rather we want to compute the forces (Fi) that must have existed to produce the set of voltages (Vj) that are

measured. The measured voltages Vj now are the inputs to the matrix, and the forces Fi are the outputs.

where Fi = Vj / S(i,j) = Vj * B(i,j) or Fi= Sum(Bij*Vj)

and B(i,j) is the "matrix inverse" of the sensitivity matrix S(i,j)

		VFx	VFy	VFz	VMx	VMy	VMz
		j = 1	2	3	4	5	6
Fx	i = 1	B11	B12	B13	B14	B15	B16
Fy	2	B21	B22	B23	B24	B25	B26
Fz	3	B31	B32	B33	B34	B35	B36
Mx	4	B41	B42	B43	B44	B45	B46
My	5	B51	B52	B53	B54	B55	B56
Mz	6	B61	B62	B63	B64	B65	S66

Thus, for instance, to compute the input force Fz (I= 3 for output Fz):

Fz = Sum(B3,j*Vj)
Fz = B31*V1 + B32*V2 + B33*V3 + B34*V4 + V35*V5 + B36*V6

CALIBRATION TESTS

In addition to the tests required to determine the force - voltage relationships discussed above, the AMTI calibration routine may include a number of other test procedures. These include:

1. Assure that all channels are functioning properly.
2. Test for level of signal drift and noise.
3. Test for zero-shift at 150% full scale loads.
4. Conduct primary force/voltage sensitivity calibration and analyze the data.
5. On large units carry out a surface grid-map load-location test.
6. Measure the resonant frequencies.
7. Run x,y,z linearity and hysteresis tests.

FORCE AND MOTION

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Multi-axis Force Transducer Calibration Data
Model: BP600900-2000-CTT Serial Number: 7386M

Calibration Filed under 7386M.1
Calibrated on: 7/6/2011

GENERAL USE (Only main sensitivity terms)

The 'Sensitivities' (output/input) for each channel are:

-------- Forces --------			-------- Moments --------		
	uV/V x N	uV/V x lb		uV/V x N-m	uV/V x in-lb
Fx	.3464	1.5407	Mx	.4656	.0526
Fy	.3474	1.5453	My	.5282	.0597
Fz	.0886	.3942	Mz	1.0375	.1172

Location of the center of the top plate relative
to the effective XYZ center of the transducer.

xo = 0.247 yo = -0.705 zo = -55.296 [millimeters]
xo = 0.010 yo = -0.028 zo = -2.177 [inches]

ADVANCED USE (Sensitivity Matrix Analysis) 7386M

SI Units: SENSITIVITY MATRIX S(i, j)
Output of channel i (uV/Vex) is S(i,j) times the
mechanical input j (N, N-m)

j / i	Fx	Fy	Fz	Mx	My	Mz
Vfx|	.3464	-.0002	-.0007	.0011	-.0002	-.0160
Vfy|	.0015	.3474	-.0001	.0005	-.0017	.0082
Vfz|	-.0006	-.0009	.0886	-.0015	-.0003	-.0021
Vmx|	.0002	.0017	-.0003	.4656	-.0013	.0032
Vmy|	.0019	-.0009	-.0001	-.0007	.5282	.0002
Vmz|	.0001	.0000	.0001	-.0066	.0030	1.0375

SI Units: INVERTED SENSITIVITY MATRIX B(i, j)
Input to channel i (N, N-m) is B(i,j) times the
electrical output j (uV/Vex)

j / i	VFx	VFy	VFz	VMx	VMy	VMz
fx|	2.8871	.0013	.0219	-.0059	.0009	.0446
fy|	-.0125	2.8785	.0032	-.0036	.0094	-.0228
fz|	.0178	.0278	11.2826	.0364	.0068	.0233
mx|	-.0010	-.0104	.0080	2.1476	.0054	-.0066
my|	-.0105	.0047	.0027	.0027	1.8934	-.0006
mz|	-.0003	-.0001	-.0015	.0136	-.0054	.9638

USC Units: SENSITIVITY MATRIX S(i, j)
Output of channel i (uV/Vex) is S(i,j) times the
mechanical input j (lb/in-lb)

j / i	Fx	Fy	Fz	Mx	My	Mz
Vfx|	1.5407	-.0007	-.0030	.0001	.0000	-.0018
Vfy|	.0067	1.5453	-.0004	.0001	-.0002	.0009
Vfz|	-.0025	-.0038	.3942	-.0002	.0000	-.0002
Vmx|	.0007	.0075	-.0015	.0526	-.0002	.0004
Vmy|	.0085	-.0039	-.0006	-.0001	.0597	.0000
Vmz|	.0005	.0001	.0006	-.0007	.0003	.1172

USC Units: INVERTED SENSITIVITY MATRIX B(i, j)
Input of channel i (uV/Vex) is B(i,j) times the
electrical output j (uV/Vex)

j / i	VFx	VFy	VFz	VMx	VMy	VMz
fx|	.6491	.0003	.0049	-.0013	.0002	.0100
fy|	-.0028	.6471	.0007	-.0008	.0021	-.0051
fz|	.0040	.0062	2.5366	.0082	.0015	.0052
mx|	-.0086	-.0918	.0704	19.0083	.0479	-.0582
my|	-.0926	.0419	.0241	.0243	16.7586	-.0054
mz|	-.0027	-.0013	-.0136	.1202	-.0475	8.5306

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Multi-axis Force Transducer Calibration Data
Model: BP600900-2000-CTT Serial Number: 7387M

Calibration Filed under 7387M.1
Calibrated on: 7/6/2011

GENERAL USE (Only main sensitivity terms)

The 'Sensitivities' (output/input) for each channel are:

-------- Forces --------			-------- Moments --------		
	uV/V x N	uV/V x lb		uV/V x N-m	uV/V x in-lb
Fx	.3433	1.5269	Mx	.4596	.0519
Fy	.3406	1.5148	My	.5226	.0590
Fz	.0876	.3897	Mz	1.0401	.1175

Location of the center of the top plate relative
to the effective XYZ center of the transducer.

xo = 1.944 yo = -1.663 zo = -54.529 [millimeters]
xo = 0.077 yo = -0.065 zo = -2.147 [inches]

ADVANCED USE (Sensitivity Matrix Analysis) 7387M

SI Units: SENSITIVITY MATRIX S(i, j)
Output of channel i (uV/Vex) is S(i,j) times the
mechanical input j (N, N-m)

j / i	Fx	Fy	Fz	Mx	My	Mz
Vfx|	.3433	-.0043	.0003	.0001	-.0013	-.0157
Vfy|	.0044	.3406	-.0006	.0029	.0006	.0028
Vfz|	.0006	-.0008	.0876	.0005	-.0007	-.0016
Vmx|	.0006	.0006	-.0008	.4596	.0023	.0006
Vmy|	.0007	.0000	-.0010	-.0047	.5226	.0003
Vmz|	-.0028	-.0040	.0000	-.0003	.0030	1.0401

SI Units: INVERTED SENSITIVITY MATRIX B(i, j)
Input to channel i (N, N-m) is B(i,j) times the
electrical output j (uV/Vex)

j / i	VFx	VFy	VFz	VMx	VMy	VMz
fx|	2.9129	.0376	-.0098	-.0006	.0071	.0438
fy|	-.0381	2.9358	.0191	-.0185	-.0035	-.0086
fz|	-.0187	.0266	11.4144	-.0136	.0159	.0177
mx|	-.0036	-.0041	.0189	2.1759	-.0094	-.0013
my|	-.0041	.0000	.0224	.0195	1.9135	-.0006
mz|	.0076	.0115	.0001	.0004	-.0055	.9615

USC Units: SENSITIVITY MATRIX S(i, j)
Output of channel i (uV/Vex) is S(i,j) times the
mechanical input j (lb/in-lb)

j / i	Fx	Fy	Fz	Mx	My	Mz
Vfx|	1.5269	-.0193	.0014	.0000	-.0001	-.0018
Vfy|	.0198	1.5148	-.0025	.0003	.0001	.0003
Vfz|	.0025	-.0035	.3897	.0001	-.0001	-.0002
Vmx|	.0025	.0028	-.0034	.0519	.0003	.0001
Vmy|	.0032	-.0001	-.0045	-.0005	.0590	.0000
Vmz|	-.0123	-.0180	.0000	.0000	.0003	.1175

USC Units: INVERTED SENSITIVITY MATRIX B(i, j)
Input of channel i (uV/Vex) is B(i,j) times the
electrical output j (uV/Vex)

j / i	VFx	VFy	VFz	VMx	VMy	VMz
fx|	.6549	.0085	-.0022	-.0001	.0016	.0098
fy|	-.0086	.6600	.0043	-.0042	-.0008	-.0019
fz|	-.0042	.0060	2.5662	-.0031	.0036	.0040
mx|	-.0315	-.0364	.1669	19.2588	-.0828	-.0113
my|	-.0366	.0002	.1981	.1730	16.9361	-.0053
mz|	.0672	.1018	.0007	.0036	-.0491	8.5105

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Multi-axis Force Transducer Calibration Data

Model: BP600900-2000-CTT Serial Number: 9551M

Calibration Filed under 9551M.1 #8

Calibrated on: 4/23/2014

GENERAL USE (Only main sensitivity terms)

The 'Sensitivities' (output/input) for each channel are:

-------- Forces --------			-------- Moments --------		
	uV/V x N	uV/V x lb		uV/V x N-m	uV/V x in-lb
Fx	.34652	1.54132	Mx	.46270	.05228
Fy	.34569	1.53764	My	.52670	.05951
Fz	.08767	.38994	Mz	1.04841	.11845

Location of the center of the top plate relative to the effective XYZ center of the transducer.

xo = 0.437 yo = -1.033 zo = -58.772 [millimeters]

xo = 0.017 yo = -0.041 zo = -2.314 [inches]

ADVANCED USE (Sensitivity Matrix Analysis) 9551M

SI Units: SENSITIVITY MATRIX S(i, j)
Output of channel i (uV/Vex) is S(i,j) times the
mechanical input j (N, N-m)

j / i	Fx	Fy	Fz	Mx	My	Mz
Vfx|	.34652	-.00092	-.00029	-.00020	.00321	-.01285
Vfy|	-.00012	.34569	-.00027	-.00171	-.00335	.01184
Vfz|	-.00074	-.00043	.08767	.00128	-.00042	-.00117
Vmx|	-.00096	-.00015	-.00048	.46270	.00117	.00455
Vmy|	-.00017	.00044	-.00023	-.00279	.52670	-.00236
Vmz|	-.00113	-.00015	.00060	-.00584	-.00434	1.04841

SI Units: INVERTED SENSITIVITY MATRIX B(i, j)
Input to channel i (N, N-m) is B(i,j) times the
electrical output j (uV/Vex)

j / i	VFx	VFy	VFz	VMx	VMy	VMz
fx|	2.88597	.00773	.00921	.00156	-.01724	.03525
fy|	.00097	2.89272	.00935	.01036	.01812	-.03265
fz|	.02428	.01425	11.40672	-.03125	.00929	.01304
mx|	.00599	.00097	.01186	2.16104	-.00489	-.00931
my|	.00099	-.00241	.00501	.01147	1.89861	.00426
mz|	.00314	.00040	-.00640	.01211	.00781	.95382

USC Units: SENSITIVITY MATRIX S(i, j)
Output of channel i (uV/Vex) is S(i,j) times the
mechanical input j (lb/in-lb)

j / i	Fx	Fy	Fz	Mx	My	Mz
Vfx|	1.54132	-.00409	-.00128	-.00002	.00036	-.00145
Vfy|	-.00054	1.53764	-.00122	-.00019	-.00038	.00134
Vfz|	-.00329	-.00191	.38994	.00014	-.00005	-.00013
Vmx|	-.00428	-.00067	-.00213	.05228	.00013	.00051
Vmy|	-.00076	.00196	-.00102	-.00031	.05951	-.00027
Vmz|	-.00503	-.00065	.00266	-.00066	-.00049	.11845

USC Units: INVERTED SENSITIVITY MATRIX B(i, j)
Input of channel i (uV/Vex) is B(i,j) times the
electrical output j (uV/Vex)

j / i	VFx	VFy	VFz	VMx	VMy	VMz
fx|	.64882	.00174	.00207	.00035	-.00388	.00793
fy|	.00022	.65034	.00210	.00233	.00407	-.00734
fz|	.00546	.00320	2.56446	-.00702	.00209	.00293
mx|	.05303	.00860	.10497	19.12740	-.04326	-.08241
my|	.00878	-.02132	.04435	.10151	16.80464	.03772
mz|	.02776	.00355	-.05665	.10723	.06913	8.44224

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Multi-axis Force Transducer Calibration Data

Model: BP600900-2000-CTT Serial Number: 9136M

Calibration Filed under 9136M.1 #5

Calibrated on: 3/22/2014

GENERAL USE (Only main sensitivity terms)

The 'Sensitivities' (output/input) for each channel are:

-------- Forces --------		-------- Moments --------	
uV/V x N	uV/V x lb	uV/V x N-m	uV/V x in-lb
Fx .34383	1.52935	Mx .45489	.05139
Fy .34461	1.53283	My .51867	.05860
Fz .08710	.38744	Mz 1.04341	.11789

Location of the center of the top plate relative
to the effective XYZ center of the transducer.

xo = 0.825 yo = 0.266 zo = -58.558 [millimeters]

xo = 0.032 yo = 0.010 zo = -2.305 [inches]

ADVANCED USE (Sensitivity Matrix Analysis) 9136M

SI Units: SENSITIVITY MATRIX S(i, j)
Output of channel i (uV/Vex) is S(i,j) times the
mechanical input j (N, N-m)

j / i	Fx	Fy	Fz	Mx	My	Mz
Vfx|	.34383	.00063	-.00039	-.00042	-.00101	-.01895
Vfy|	.00174	.34461	.00028	-.00317	.00136	-.00109
Vfz|	-.00076	-.00059	.08710	.00072	.00215	-.00162
Vmx|	-.00215	.00040	.00012	.45489	.00383	.00090
Vmy|	.00046	.00088	-.00043	-.00091	.51867	.00021
Vmz|	-.00023	.00051	.00001	.00304	.00350	1.04341

SI Units: INVERTED SENSITIVITY MATRIX B(i, j)
Input to channel i (N, N-m) is B(i,j) times the
electrical output j (uV/Vex)

j / i	VFx	VFy	VFz	VMx	VMy	VMz
fx|	2.90852	-.00539	.01314	.00226	.00526	.05284
fy|	-.01454	2.90182	-.00941	.02018	-.00775	.00274
fz|	.02532	.01973	11.48031	-.01821	-.04751	.01834
mx|	.01374	-.00256	-.00307	2.19829	-.01619	-.00165
my|	-.00252	-.00493	.00947	.00381	1.92793	-.00043
mz|	.00062	-.00139	-.00016	-.00642	-.00642	.95841

USC Units: SENSITIVITY MATRIX S(i, j)
Output of channel i (uV/Vex) is S(i,j) times the
mechanical input j (lb/in-lb)

j / i	Fx	Fy	Fz	Mx	My	Mz
Vfx|	1.52935	.00280	-.00175	-.00005	-.00011	-.00214
Vfy|	.00773	1.53283	.00124	-.00036	.00015	-.00012
Vfz|	-.00339	-.00262	.38744	.00008	.00024	-.00018
Vmx|	-.00954	.00180	.00054	.05139	.00043	.00010
Vmy|	.00205	.00393	-.00190	-.00010	.05860	.00002
Vmz|	-.00103	.00227	.00006	.00034	.00040	.11789

USC Units: INVERTED SENSITIVITY MATRIX B(i, j)
Input of channel i (uV/Vex) is B(i,j) times the
electrical output j (uV/Vex)

j / i	VFx	VFy	VFz	VMx	VMy	VMz
fx|	.65389	-.00121	.00295	.00051	.00118	.01188
fy|	-.00327	.65239	-.00212	.00454	-.00174	.00061
fz|	.00569	.00443	2.58101	-.00409	-.01068	.00412
mx|	.12162	-.02270	-.02713	19.45708	-.14332	-.01457
my|	-.02226	-.04362	.08378	.03368	17.06414	-.00379
mz|	.00552	-.01235	-.00139	-.05685	-.05683	8.48293