TRANSDUCER INSTRUCTIONS

Single Element Multi-Component Transducer

Model: UDW3

Serial Number _______

November 24, 2009

176 Waltham Street
Watertown, Massachusetts 02472
USA

Table of Contents

1.0 General Description

The AMTI UDW3 is a multi-component transducer produced with six channels of output – three force channels Fx, Fy, Fz and three moment channels, Mx, My and Mz.

The model number designation UDW3-XXXX refers to the size and capacity. The designation UDW indicates an underwater transducer. The character directly following the UDW refers to the maximum diameter or lateral dimension of the unit. For example, the UDW3 has a 3-inch diameter body. The last group of numbers and letters refers to the vertical load capacity. For example, "-500" indicates a 500 pound rating. The ratings are always given for the vertical (Fz) load. For underwater transducers, unless the customer asks for a specific material, the body is stainless steel and rated for applications involving submersion in fresh water.

A brochure and dimensional outline drawing (drawing number 25K-A-31443) of this sensor showing the overall dimensions, mounting holes, and coordinate system convention are included in Appendix A. Also in Appendix A is a table showing the position and value of the loads during calibration, and the pinout for the connector. The transducer construction consists of a single cylindrical strain element. Strain gages are placed on the outer diameter of the strain element and wired in four-arm bridges. The wiring is attached to the connector at the bottom. The bottom of the element is attached to a flange that contains mounting holes and the electrical connector. The top of the element is attached to a stainless housing that also provides mounting holes for load attachment. A cylindrical piece that forms the sides of the transducer is captured between the top housing and the bottom flange. Sealing is accomplished using o-rings. The transducer incorporates a unique design that essentially eliminates the effect of pressure on the output. A bladder is installed inside the transducer so that the external surface of the bladder communicates with the inside of the transducer and the internal surface of the bladder communicates with the environment. The transducer internal passages (in communication with the external bladder surface) are filled with mineral oil. The internal passage of the bladder is exposed to the environment (water pressure) through a sealed passage in the transducer body. The bladder expands and contracts with the increase and decrease in pressure keeping zero pressure difference across the strain element. Thus the design eliminates pressure-induced loads on the three forces and moments. The transducer is calibrated after it is assembled and filled with mineral oil. Except for the connector all parts are stainless steel and rated for use in water. The connector is hermetically sealed and its metal jacket is tin plated steel. The use of some non-soluble grease on the connector body is recommended to prevent long-term corrosion.

2. Installation and Operation

2.1 Installation

The transducer should be mounted between the load input and output devices using the threaded holes provided and described in the drawing of Appendix A. It is important that the surfaces to be attached are flat, clean, and lubricant free. Any movement of the transducer relative to the mounting surfaces during loading could cause unwanted hysteresis and zero shift during a measurement.

Recommended bolt tightening for the transducer depends on the size of the bolt, material, grade, bolt lubricant, use of inserts (helicoil) etc. The notes of Appendix A make suggestions for the recommended torque for the specific transducer and fastener indicated. Since the user will be performing the installation, they must follow their own guidelines for the fastener and conditions present at the installation. Ours is simply one method for fastening and is not necessarily the best for the installation. The user is the best judge of this. If unsure of how to best install the transducer please contact AMTI.

One important consideration in the operation of the transducer is the environmental conditions. The obvious concern is that the transducer be operated as intended and in the environment for which it was designed. Less obvious is the effect of some of the more subtle factors. One such factor is temperature. While the transducer output is not very temperature dependent, if possible the transducer should be in thermal equilibrium. Output data during swings in temperature may result in zero shift errors. In general, this is true not only of the sensors, but also the electrical conditioning equipment such as amplifiers. It is recommended that the system be turned on and left to stabilize for at least one hour before taking data. In fact, unless circumstances will not allow it, it is recommended that the system be left on continuously during long duration test periods.

A multi-component transducer is a sophisticated device and making recommendations for safe overloads are difficult. In addition, there is confusion between "overload limit", "factor of safety", etc. First a clarification of the difference between "factor of safety" and "overload limit" should be made. "Factor of safety" is a common engineering term and is somewhat a misnomer. The "factor of safety" is the ratio of the yield strength divided by the design stress. When we design a transducer, the strain elements are designed to reach the yield strength at three (3) times the design stress. **This does not mean that the transducer can be subjected to three (3) times the load without damaging the transducer.** The yield strength can vary, so AMTI recommends the use of the "overload limit" to define safe loads to which the transducer can be subjected. The listed capacities for uni-directional loading can be exceeded by 50% (1.5 times rated capacity) without damaging the transducer. It should be pointed out that the transducer is not calibrated above its rated capacity[1]. The "overload limit" only relates to avoiding damage and not extending the useful range. The first evidence of serious overload will be

[1] It may actually be calibrated for full output below its capacity if requested by the customer.

a significant zero shift. This does not always indicate permanent damage, however, it should be recalibrated.

Warning! Extremely high impulse forces will result if the dynamometer is dropped. These are rugged instruments and should provide years of trouble-free operation when handled correctly. However, because of its mass, forces exceeding its safe range may result due to rapid deceleration upon being dropped onto a hard surface for even a short distance.

2.2 Operation

These instruments use metal foil strain gages to measure the forces and moments present. Strain gages are resistive elements that when "strained" change in resistance. Properly placed gages can provide information on strains in several directions. The measurement is accomplished by placing these gages in wheatstone bridges and applying an excitation voltage to the input of the bridge and measuring the output voltage at the bridge output. The output of the gages is very low and must be amplified to provide a useful output. Typical amplifier gains can range up to 4000. A discussion of the operation of AMTI or other manufacturer's amplifiers can be found in the amplifier operating manual.

The basic output of the strain gages is the gage sensitivity(s). This term is expressed as follows:

<u>For Forces</u>

S = microVolts/Volt(Excitation)-lb
S = microVolts/Volt(Excitation)-N

<u>For Moments</u>

S = microVolts/Volt(Excitation)-lb-in
S = microVolts/Volt(Excitation)-N-m

When your dynamometer is delivered, the values of the calibrated sensitivities are provided in Appendix B. The calibration procedure will be explained in Section 3. The governing equation that shows the relationship among the load, sensitivity, gain, output voltage, and excitation voltage is presented below:

$$F_f\,(\text{Load}) = V_{fout}/(V_{fexc} * S_f * G_f * 1\text{x}10^{-6})$$

where:

- F_f is the load in the f direction in pounds or Newtons
- V_{fout} is the amplified voltage output for the f channel in volts.
- V_{fexc} is the excitation voltage applied to the bridge in volts
- G_f is the amplifier gain

- S_f is the calibrated gain sensitivity in microVolts/Vexc-lb
or
- S_f is the calibrated gain sensitivity in microVolts/Vexc-N

For moments the above equations are the same except the moment sensitivities (S_m) are used and the resultant output is the moment M_m.

One important factor to keep in mind is that the gain and excitation voltage may differ for each channel. Thus the subscripts f and m are usually replaced by the load or moment direction x, y, or z.

3.0 Calibration

3.1 Calibration Procedure

AMTI calibrates every sensor it manufactures to rigorous industry standards. Our calibration facility and equipment is ISO 9001 certified and surveyed every six months. All of the equipment used in the manufacture of our sensors and the calibration equipment are on an annual calibration schedule.

The transducers are typically calibrated in eight (8) different load locations which will provide data for Fx, Fy, Fz, Mx, My, Mz, -Mx, and -My. The calibration sheets provided in Appendix C will indicate the loads used for this particular dynamometer. The loads are applied the same way for all standard transducers and the specific details are provided in Appendix A. The general procedure will be described in this section.

First a description of the axes convention is given. Figure 1 shows the X, Y, and Z conventions of the transducers AMTI manufactures. The standard right hand rule is followed as the axis convention. The positive Fz axis always points vertically down in our transducers. If the transducer has a side electrical connector then the positive Y axis points in the direction of the transducer from the side of the transducer with the connector. The +X axis is to the left of the +Y axis as shown in the figure. The axis location can always be found in the transducer drawing or brochure for the specific transducer.

The location of the true X and Y plane is approximately the midpoint of the transducer along the Z axis. Included in every calibration is the geometric location of this origin relative to the top of the sensor, along the Z axis. It can be found in Table B.1 of Appendix B.

In the calibration procedure the Z load locations are referenced to the top of the dynamometer rather than the center of the transducer. This is an artifact of the calibration procedure and should not be confused with the true origin. Another feature of our calibration procedure is the use of fixtures to apply the loads. In general the dynamometer is mounted between plates to which loads are precisely applied using fixtures that insure

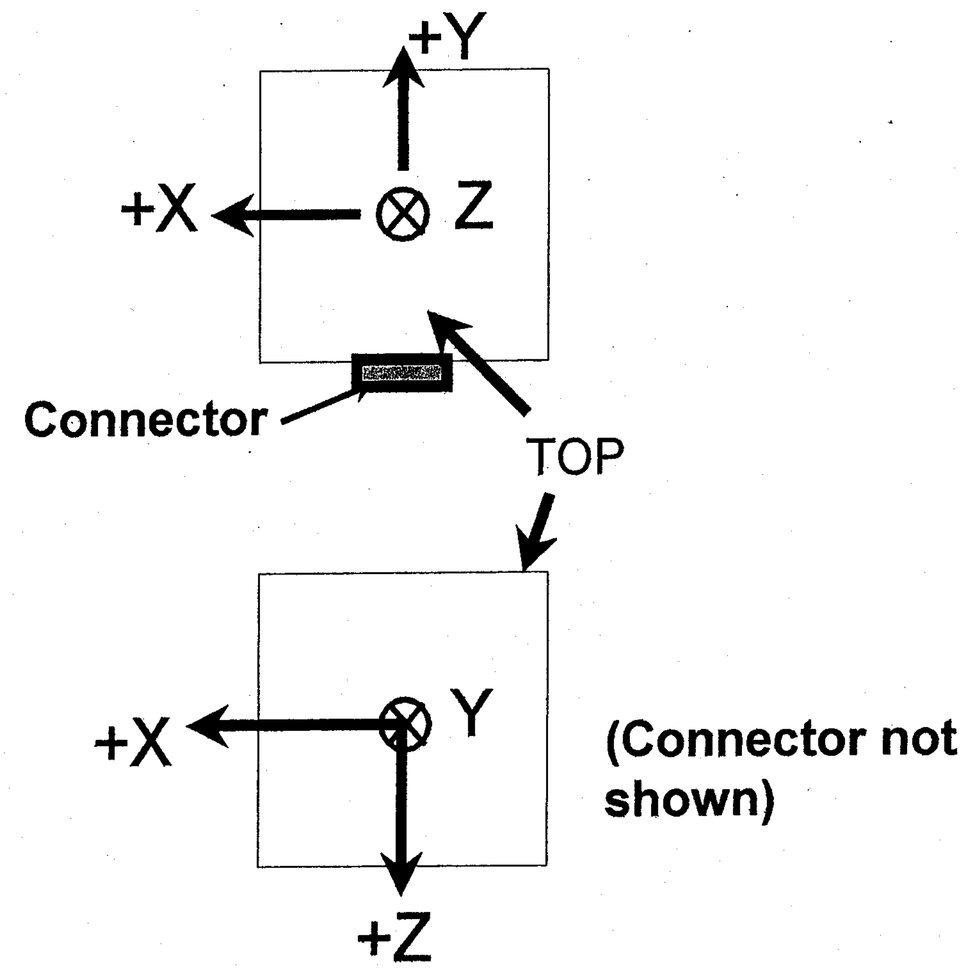

Fig. 1 Axis Convention

the application of pure loads in the direction applied. One can see the difficulty in trying to directly apply a load to a round transducer.

In general a 10 point calibration is performed for each load location. The transducer is installed into the calibration stand. Prior to applying the load zeros are taken. The load is then slowly applied up to the specified maximum working load.[2] As the load increases the computerized calibration system takes data at 10% increments of the maximum load up to 100% and then takes the same data as the load is released slowly. This is referred to as a "10 point" calibration. All channels of data are taken for every load point. This data is presented in Appendix C.

Following is a description of the applied loads in the Fx, Fy, Fz, Mx, My, Mz, -Mx, and –My directions. Your calibration may only include some of these depending on the specification of your transducer. The location of the loads is shown as x, y, and z in the following figures. The numeric values of the location and magnitude of the loads can be found in Appendix A.

Fx & Fy Loads

The upper left corner of Figure 2 shows the application of the Fx calibration load. Two views of the transducer are shown, the top view and the side view. As can be seen in the figure, the Fx force is applied in the +X direction at Y=0, X=-x, and Z=+z. The x, y, or z dimensions listed in Appendix A for your transducer may exceed the linear dimension of the transducer. This is because the calibration fixture to which the load was applied usually has greater dimensions than the sensor. The actual locations of the Fx (and other loads) are given in Appendix A. The Fy calibration loading can be found in the upper right of Fig. 2. It is basically the same as the Fx except rotated 90 degrees.

Fz Load

The application of the Fz load is at the geometric center of the top pushing down in the +Z direction. The coordinates for the location relative to the top are X=0, Y=0, and Z=0. Some explanation is required at this point. The preceding dimensions are given relative to the center of the **top**. These dimensions are not referenced to the origin. The actual calibrations will provide the exact location of the effective X,Y, and Z origin. The effective location of the origin is determined using the Mx and My sensitivities to calculate the actual zero position when the Fz force is applied.

[2] This may or may not be equal to the maximum rated load. The customer can specify a different maximum load for calibration if they desire.

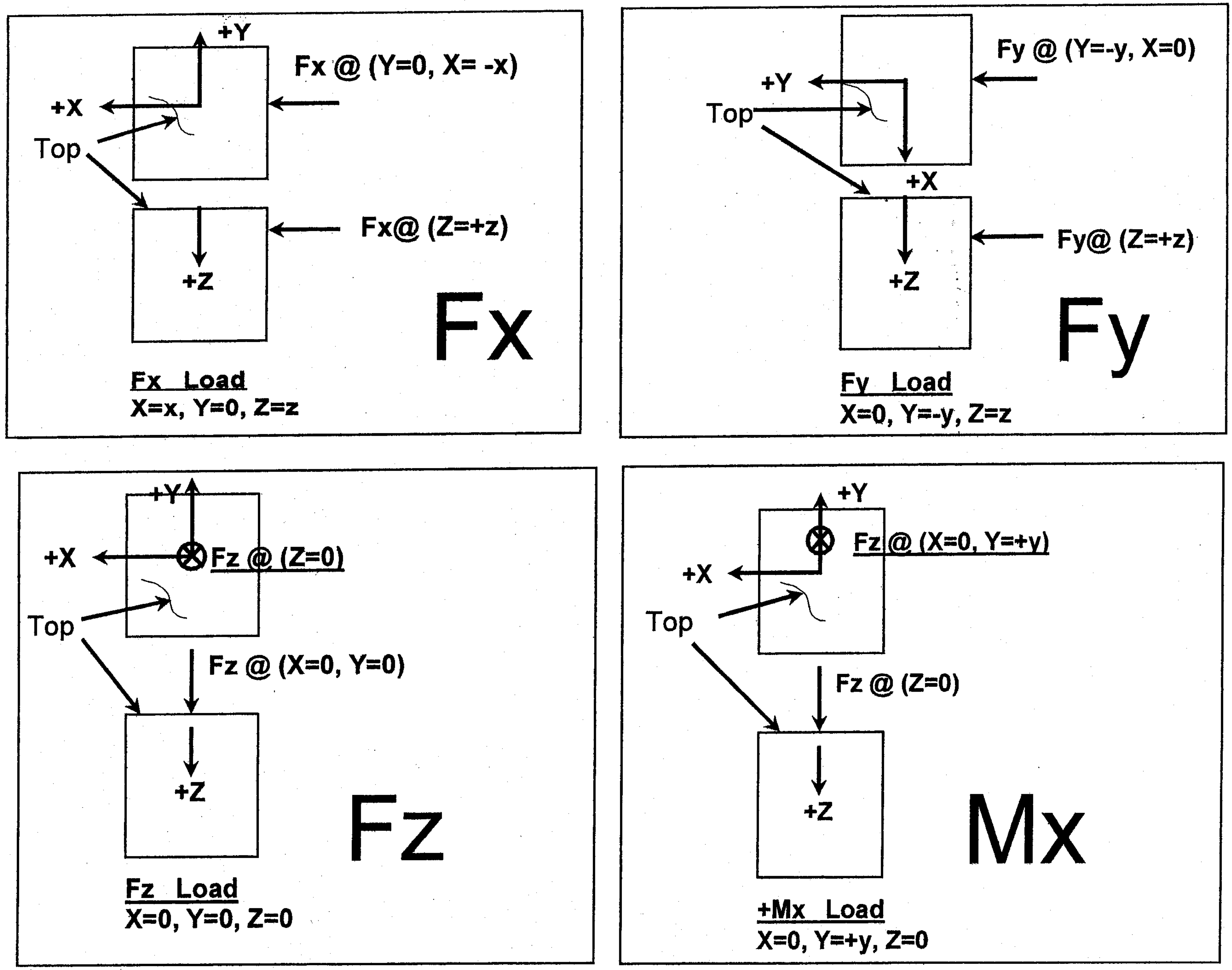

Fig. 2 Application of Fx, Fy, Fz, and Mx Loads

Mx Moment

The Mx moment is generated by applying an Fz load along the Y axis as shown in the lower right figure of Figure 2. The Fz load is applied in the positive Z direction at Y= +y and X=0. Using the "right hand rule" this result in a positive Mx moment.

My Moment

Like the Mx load the My moment is generated by an Fz load but on the X Axis as shown in the top right figure of Figure 3. The Fz load is applied in the positive Z direction at Y=0 and X=-x. Using the "right hand rule" this result in a positive My moment.

Mz Moment

The Mz moment is generated using an Fx load as shown in the top right sketch of Figure 3. The Fx load is applied +z down from the top surface. As mentioned before, the application of the loads are described from the top surface. The actual moment is reference to the z origin located at a moment arm Z3 between the Fx force and the origin.

-Mx Moment

The –Mx moment has the same load conditions described for the Mx moment, except that the force is applied at a -y location.

-My Moment

The –My moment has the same load conditions described for the My moment except that the force is applied at a +x location.

3.2 Main Sensitivity Terms

The first step in the calibration after the loads have been applied is to determine the main sensitivity terms. The equation that defines the relationship between the various terms is:

For forces:

$$F_f\ (\text{Load}) = V_{fout}/(V_{fexc} * S_f * G_f * 1\text{x}10^{-6})$$

For moments:

$$M_m\ (\text{Load}) = V_{mout}/(V_{mexc} * S_m * G_m * 1\text{x}10^{-6})$$

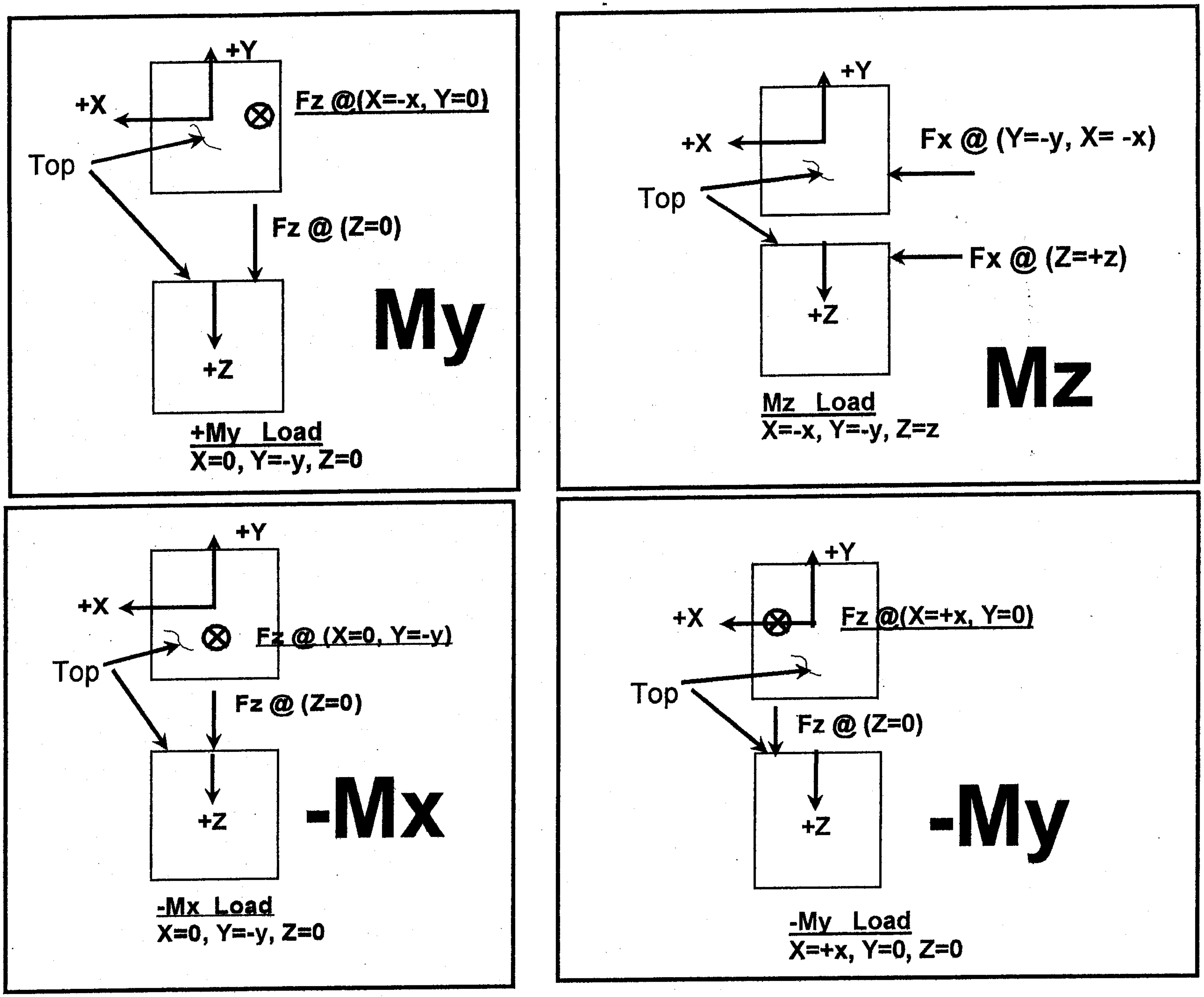

Fig. 3 Application of My, Mz, -Mx, and -My Loads

Where:

F_f = Applied calibrated load (lb or N). In general, the load used to calculate the sensitivity is the rated load for that channel of the transducer.

M_m = Applied moment using a calibrated load applied at a precise distance. In general, the moment used to calculate the sensitivity is the rated moment for that channel of the transducer.

S_f is the sensitivity of F_f in microVolts /V_{exc}-lb or microVolts/V_{exc}-N

V_{fout} is the output voltage for an F_f load

V_{fexc} is the excitation voltage on the F_f channel

G_f is the gain on the F_f channel.

S_m is the sensitivity of M_m in microVolts /V_{exc}- in-lb or microVolts/V_{exc}-N-m

V_{mout} is the output voltage for an M_m moment

V_{mexc} is the excitation voltage on the M_m channel

G_m is the gain on the M_m channel.

The sensitivity equations for F_x, F_y, F_z, M_x, M_y, and M_z are:

$$S_{fx} = V_{fxout}/(F_x*V_{fxexc}*G_{fx}*1*10^{-6})$$

$$S_{fy} = V_{fyout}/(F_y*V_{fyexc}*G_{fy}*1*10^{-6})$$

$$S_{fz} = V_{fzout}/(F_z*V_{fzexc}*G_{fz}*1*10^{-6})$$

$$S_{mx} = V_{mxout}/(M_x*V_{mxexc}*G_{mx}*1*10^{-6})$$

$$S_{my} = V_{myout}/(M_y*V_{myexc}*G_{my}*1*10^{-6})$$

$$S_{mz} = V_{mzout}/(M_z*V_{mzexc}*G_{mz}*1*10^{-6})$$

Using the following equation the load can be calculated from the measured output voltage using the following equation for forces:

$$F_f\,(Load) = V_{fout}/(V_{fexc}*S_f*G_f*1x10^{-6})$$

Or

The following equation for moments:

$$M_m \text{ (moment)} = V_{mout} / (V_{mexc} * S_m * G_m * 1x10^{-6})$$

The main sensitivity terms for the calibrated transducer accompanying this report are provided in the top of the Table B.1 in Appendix B. In general, these can be used with the preceding equations to calculate with great accuracy the forces and moments measured by the transducer.

These terms are individually calculated for each load. When these equations are used, the assumption is made that each axis is independent of the others. That is, there is no cross talk between channels. In general this is a good assumption. These are usually sufficient to predict forces in the direction of load to errors of less than 1 percent of full load and less than 2% cross talk. However, if the user wants to insure the greatest degree of accuracy then they are directed to the section which presents the concept of a Sensitivity matrix and its inverse, the Cross Talk matrix.

Geometric vs. "Effective Origin" or Center

The center of the top surface of the transducer is a convenient reference point for the X, Y, and Z origin. The actual origin, however, is located a distance along the Z-axis which makes the X-Y plane location beneath the top surface of the transducer by a distance z_o in the positive Z direction. Horizontal loads applied at this z_o distance will result in zero Mx or My moment output. The Z-axis can usually be assumed to lie along the geometric centerline of the transducer. Small deviations x_o and y_o from the centerline are also calculated. A vertical Fz force applied at x_o and y_o will result in zero Mx and My moment outputs. All three (x_o, y_o, and z_o) values are presented in Table B.1 of Appendix B.

3.3 Cross-Talk Matrix

As previously mentioned, using the Main Sensitivity terms based on a single load is adequate for most applications. If there is cross-talk due to unusual loading conditions the user can use a "cross-talk" matrix to correct for this effect. Table B.2 of Appendix B presents two matrices, the Sensitivity Matrix (S(i,j)) and the "inverse" Sensitivity Matrix (B(i,j)) in both English and metric units. The derivation of the Sensitivity Matrix is beyond the scope of this report, but it adjusts the sensitivities to compute "influence coefficients" that correct for any cross talk present.

The Sensitivity Matrix (S(i,j)) shows the relationship between the voltage output for each force and any cross talk voltages resulting for the application of the force load. The relevant equations are as follows:

V_F (Output Volt.) =

$$(S_{ij}*F_x*CF_{Fx})+(S_{ij}*F_y*CF_{Fy})+(S_{ij}*F_z*CF_{Fz})+(S_{ij}*M_x*CF_{Mx})+(S_{ij}*M_y*CF_{My})+(S_{ij}*M_z*CF_{Mz})$$

(Where CF= Gain* V(excitation)* $1*10^{-6}$)

While the sensitivity matrix shows the relationship between the Voltage output and the different parameters, the user is more interested in the relationship between the measured load and the voltage. Thus the inverse of the Sensitivity Matrix or B(i,j) is of more use. This inverse matrix is also presented in Table B.2.

Inverse Sensitivity Matrix (Bi,j)

	V_{fx}	V_{fy}	V_{fz}	V_{mx}	V_{my}	V_{mz}
F_x	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	B_{16}
F_y	B_{21}	B_{22}	B_{23}	B_{24}	B_{25}	B_{26}
F_z	B_{31}	B_{32}	B_{33}	B_{34}	B_{35}	B_{36}
M_x	B_{41}	B_{42}	B_{43}	B_{44}	B_{45}	B_{46}
M_y	B_{51}	B_{52}	B_{53}	B_{54}	B_{55}	B_{56}
M_z	B_{61}	B_{62}	B_{63}	B_{64}	B_{65}	B_{66}

The calculation of forces and moments including cross talk terms can be performed using the following equations:

F_x =

$$(B_{11}*V_{fx}/CF_{fx})+(B_{12}*V_{fy}/Cf_{fy})+(B_{13}*V_{fz}/CF_{fz})+(B_{14}*V_{mx}/CF_{mx})$$
$$+(B_{15}*V_{my}/CF_{my})+(B_{16}*V_{mz}/CF_{mz})$$

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M_z =

$$(B_{61}*V_{fx}/CF_{fx})+(B_{62}*V_{fy}/CF_{fy})+(B_{63}*V_{fz}/CF_{fz})+(B_{64}*V_{mx}/CF_{mx})+(B_{65}*V_{my}/Cf_{my})$$
$$+(B_{66}*V_{mz}/CF_{mz})$$

If the matrix with English units is used then forces and moment will be in pounds and inch-pounds respectively. If the matrix with metric units is used, then the loads and moments will be in Newtons and Newton-meters.

The user is cautioned to be consistent. If no cross talk correction is needed or used then the Main sensitivities of Table B.1 should be used. If the full cross-talk correction matrix (B(i,j)) is used, then they should use all of the terms in the calibration matrix. The two methods should not be mixed.

3.4 Ten Point Loading Tables

Tables C.1 to C.8 contain the Fx, Fy, Fz, Mx, My Mz, -Mx, and -My calibration data for the transducer. Each table contains the 10 point loading data for the transducer, which includes applying the rated load in 10% increments up to 100% of the rated load, and back down again in 10% increments to zero.

Included are the transducer output from all six channels, gain, excitation voltage, and calibration loads.

4.0 Maintenance

AMTI transducers do not require any maintenance. Theoretically a calibration should not be needed under static conditions as long as the sensor was operated in the elastic region and not damaged or subjected to gross overloads or abuse. Beyond these conditions it is up to the user to establish their own calibration period. These vary from never to once a year.

5.0 WARRANTY

Advanced Mechanical Technology, Inc. (AMTI) warrants all instruments it manufactures to be free from defects in materials and factory workmanship, and agrees to repair or replace any instrument that fails to perform as specified within one year (ten years on Biomechanics Force Platforms) after date of shipment. This warranty shall not apply to any instrument that has been:

i) repaired, worked on, or altered by persons unauthorized by AMTI in such a manner as to injure, in our sole judgment, the performance, stability, or reliability of the instrument;

ii) subjected to misuse, negligence, or accident; or

iii) connected, installed, adjusted, or used otherwise than in accordance with the instructions furnished by us.

At no charge, we will repair at our plant or at our option, replace any of our products found to be defective under this warranty.

This warranty is in lieu of any other warranty, expressed or implied. AMTI reserves the right to make any changes in the design or construction of its instruments at any time, without incurring any obligation to make any change whatever in units previously delivered.

AMTI's sole liabilities, and buyer's sole remedies, under this agreement shall be limited to the purchase price, or at our sole discretion, to the repair or replacement of any instrument that proves, upon examination, to be defective, when returned to our factory, transportation prepaid by the buyer, within one year (ten years on Biomechanics Force Platforms) from the date of original shipment.

Return transportation charges of repaired or replacement instruments under warranty will be prepaid by AMTI.

AMTI is solely a manufacturer and assumes no responsibility of any form for the accuracy of adequacy of any test results, data, or conclusions which may result from the use of its equipment.

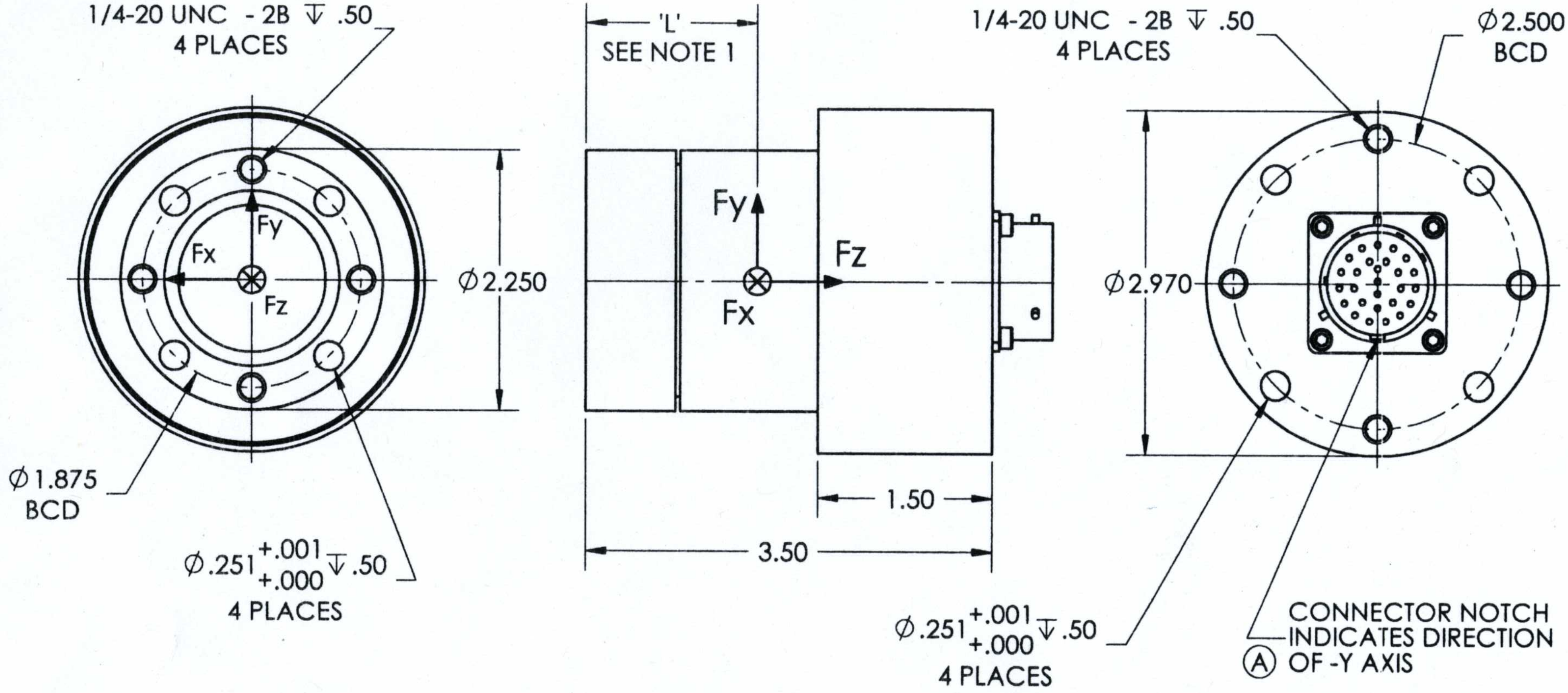
The manner in which the equipment is employed and the use to which the data and test results may be put are completely in the hands of the purchaser. AMTI shall in no way be liable for damages consequential of incidental to defects in any of its products.

This warranty constitutes the full understanding between the manufacturer and buyer, and no terms, conditions, understanding, or agreement purporting to modify or very the terms hereof shall be binding unless hereafter made in writing and signed by an authorized official of AMTI.

Appendix A

Model UDW3 Transducer Description

REVISIONS				
ECO	REV.	DESCRIPTION	DATE	APPROVED
	A	CORRECTED ORIENTATION OF CONNECTOR. ADDED AXIS ORIENTATION NOTE.	9/14/2009	FJC



NOTES:

1) DISTANCE 'L' TO ORIGIN OF TRANSDUCER PROVIDED WITH CALIBRATION.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
DECIMALS .X ± .030 .XX ± .015 .XXX ± .005
ANGLES ±1/2°
SURFACE FINISH 63
FRACTIONAL ±1/32
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL —
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	CLH	07/31/09
CHECKED		
ENG APPR.	FJC	7/31/09
MFG APPR.		
Q.A.		
COMMENTS:		

AMTI

TITLE:

UDW3

DIMENSIONAL OUTLINE

SIZE	DWG. NO.	REV
A	25K-A-31443	A

SCALE: 3:4 | WEIGHT: | SHEET 1 OF 1

1 /m

5 4 3 2 1

Transducer Load Specification

Rated maximum Loads

Transducer Model

UDW3	**-100**	**-250**	**-500**	**-1000**
Fx	**100 lb**	**250 lb**	**500 lb**	**1000 lb**
Fy	**50 lb**	**125 lb**	**250 lb**	**500 lb**
Fz	**50 lb**	**125 lb**	**250 lb**	**500 lb**
Mx	**100 in-lb**	**250 in-lb**	**500 in-lb**	**1000 in-lb**
My	**100 in-lb**	**250 in-lb**	**500 in-lb**	**1000 in-lb**
Mz	**50 in-lb**	**125 in-lb**	**250 in-lb**	**500 in-lb**

Rated loads are individually applied. The moment origin for load calculations can be taken as located at the geometric center of the transducer. The use of simultaneously applied maximum loads may result in a safety factor lower than recommended. Contact the factory for simultaneous loads above one-half the rated loads or for a check on the safety factor for specific loading conditions.

Transducer Torque Guidelines

The ¼-20 threaded holes are in 17-4 precipitation hardened stainless steel with an H900 temper. They have sufficient strength to allow loading grade 8 fasteners up to their yield point. The recommended fastener tightening torque depends upon bolt material and lubrication. To prevent possible galling, a thread lubricant should always be used. If you have bolt tightening specifications or guidelines you should follow them. If not, the following are some recommended tightening torques.

	<u>¼-20 threads:</u>
1. Oil Lubricated Grade 8 Bolt	**200 in-lb**
2. Never Seize Lubricated Grade 8 Bolt	**130 in-lb**
3. Never Seize Lubricated Austenitic Stainless Bolt	**70 in-lb**

If you have any questions please contact AMTI for technical support.

Cable Connector Pinout and Wire Color Code

Channel:	Pin:	Color:	Function:
Fx	A	Red	+ excitation
	B	Brown	- excitation
	C	Black	- output
	D	Orange	+ output
Fy	E	Red	+ excitation
	F	White	- excitation
	G	Black	- output
	H	Yellow	+ output
Fz	J	Red	+ excitation
	K	Blue	- excitation
	L	Black	- output
	M	Green	+ output
Mx	N	Red	+ excitation
	P	Yellow	- excitation
	R	Black	- output
	S	Blue	+ output
My	T	Red	+ excitation
	U	Green	- excitation
	V	Black	- output
	W	Brown	+ output
Mz	X	Red	+ excitation
	Y	Black	- excitation
	Z	Black	- output
	a	White	+ output

Appendix B

Sensitivity Terms

Appendix C

Ten Point Loading Tables