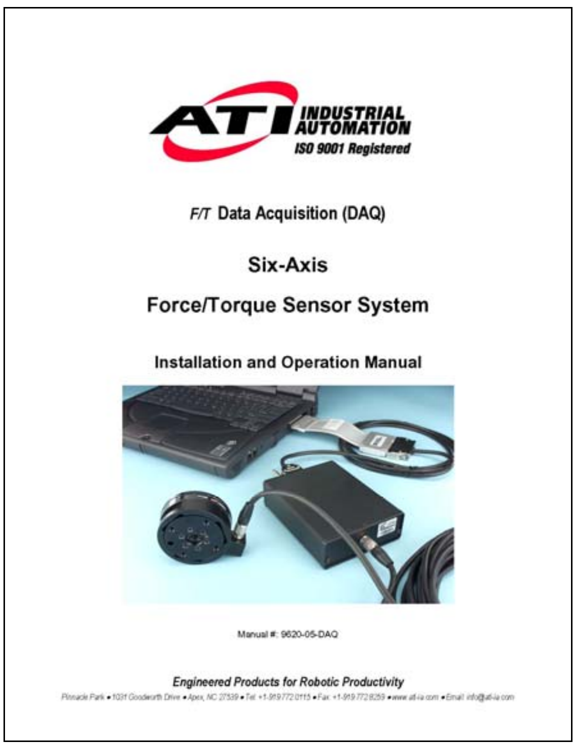
F/T Data Acquisition (DAQ)

Six-Axis Force/Torque Sensor System

Compilation of Manuals


F/T Data Acquisition (DAQ)

Six-Axis

Force/Torque Sensor System

Installation and Operation Manual

Manual #: 9620-05-DAQ

Engineered Products for Robotic Productivity

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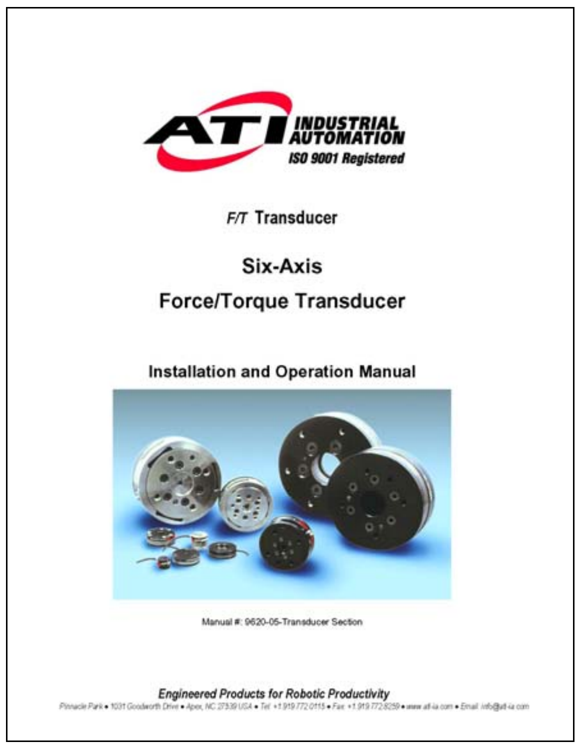
F/T Transducer

Six-Axis

Force/Torque Transducer

Installation and Operation Manual

Manual #: 9620-05-Transducer Section

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Forward

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FCC Compliance - Class B

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: 1) This device may not cause harmful interference, and 2) this device must accept any interference received, including interference that may cause undesired operation.

Any modifications to the device could impact compliance. It is the user’s responsibility to certify the device remains compliant after modifications

CE Conformity

This device complies with EMC Directive 89/336/EEC and conforms to the following standards: ENS5011:1998, ANSI C63.4:1992, ENG1000-4-2:1995, ENG1000-4-3:1995, ENG1000-4-6:1995.

Aside

Please read the manual before calling customer service. Before calling, have the following information available:

1. Serial number (e.g.; FT01234)
2. Transducer model (e.g.; Nano17, Gamma, Theta, etc.)
3. Calibration (e.g.; US-15-50:5V, SI-65-5:10V, etc.)
4. Accurate and complete description of the question or problem
5. Computer and software information. Operating system, PC type, drivers, application software and other relevant information about your configuration.

If possible be near the F/T system when calling.

⚠ **CAUTION:** Each transducer has a maximum measurement range and a maximum overload capacity. **Exceeding the transducer's overload capacity can cause permanent damage.** Smaller transducers have lower overload capacities. Torque in X and Y are usually the easiest axes to accidentally overload.

Strain gauge saturation is the first indication that you are approaching a mechanical overload condition, and saturation **always** causes inaccurate F/T data, so it is critical that you monitor the F/T system for strain gauge saturation.

How to Reach Us

Sales, Service and Information about ATI products:

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Technical support and questions:

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Fax: +1.919.772.8259
E-mail: ft_support@ati-ia.com

Quick Start

Perform the following steps to get your system installed and running on your Windows® computer system.

Installing Data Acquisition Card

1. Install the National Instruments data acquisition hardware and software following the instructions included with the National Instruments product. When finished you should have installed the data acquisition hardware and the program *Measurement & Automation* (MAX).

Installing ATI Software

2. Place the ATI Industrial Automation CD in your computer. The installation program should start automatically. If it does not start automatically you will need to run *SETUP.EXE* found in the root directory of the CD. Follow the installation instructions given by the program. This software is for Windows® 95 and later Windows® operating systems.
3. View the *README.TXT* file found in the root directory of the CD.
4. Copy your transducer's calibration file from the CD directory *Calibration* to the *ATI DAQ FT* directory on your computer (this directory was created when you installed the software). The calibration file name is based on the transducer's serial number and is in the format *FTxxxx.CAL*.

Connecting Transducer Hardware

5. Connect the transducer to the Power Supply Box or Interface Box/Power Supply with the appropriate cable.
6. Connect the Power Supply Box or Power Supply/Interface Box to the data acquisition hardware using the supplied cable.
7. Run the demo program found in the Start menu under *Programs/ATI DAQ FT/ATI DAQ FT Demo*.
8. Click on the menu *File*, then *Open Calibration*. Find the calibration data file you saved earlier and click the *Open* button.. Select the file with the name similar to *FTxxxx.CAL* and click on the *Open* button.
9. You can find program samples in the CD directory *SAMPLES*.

Please contact ATI for any information you may need for installation and configuration of your new system.

⚠ **CAUTION:** Each transducer has a maximum measurement range and a maximum overload capacity**. Exceeding the transducer's overload capacity can cause permanent damage.** Smaller transducers have lower overload capacities. Torque in X and Y are usually the easiest axes to accidentally overload. When designing your application, it is critical that you monitor the F/T system for gauge saturation to prevent an overload condition and to ensure accurate results.

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Table of Contents

Glossary of Terms

Terms	Conditions
Accuracy	See *Measurement Uncertainty*.
ActiveX Component	A reusable software component for the Windows® applications.
Compound Loading	Any load that is not purely in one axis.
DAQ	**D**ata **A**c**Q**uisition device.
FS	**F**ull-**S**cale.
F/T	Force and Torque.
Fxy	The resultant force vector comprised of components Fx and Fy.
Hysteresis	A source of measurement caused by the residual effects of previously applied loads.
IFPS	**I**nter**F**ace/**P**ower **S**upply box.
LabVIEW	A graphical programming environment created for data acquisition tasks by National Instruments.
Maximum Single-Axis Overload	The largest amount of pure load (not compound loading) that the transducer can withstand without damage.
MAP	**M**ounting **Adaptor P**late. The MAP part of the transducer is attached to the fixed surface or robot arm.
Measurement Uncertainty	The maximum expected error in measurements, as specified on the calibration certificate.
NI	**N**ational **I**nstruments Corporation, the owner of the “National Instruments” and “LabVIEW” trademarks. (www.ni.com)
Overload	The condition where more load is applied to the transducer than it can measure. This will result in saturation.
PC Card	A small computer card for use in most laptop computers.
PCMCIA Card	See *PC Card*. (PCMCIA has been renamed *PC Card* by its standards organization.)
Point of Origin	The point on the transducer from which all forces and torques are measured.
PS	**P**ower **S**upply box.
Quantization	The way the continuously variable transducer signal is converted into discreet digital values. Usually used when describing the change from one digital value to the next.
Resolution	The smallest change in load that can be measured. This is usually much smaller than accuracy.
Saturation	The condition where the transducer or data acquisition hardware has a load or signal outside of its sensing range.
Sensor System	The entire assembly consisting of parts from transducer to data acquisition card.
TAP	**T**ool **Adaptor P**late. The TAP part of the transducer is attached to the load that is to be measured.
Tool Transformation	Mathematically changing the measurement coordinate system by translating the origin and/or rotating the axes.
Transducer	The component that converts the sensed load into electrical signals.
Txy	The resultant torque vector comprised of components Tx and Ty.
Visual Basic	A Microsoft programming environment for developing Windows®-based applications.

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1. Safety

1.1 General

The customer should verify that the transducer selected is rated for the maximum loads and moments expected during operation. Refer to transducer specifications in F/T Transducer Manual (9620-05-Transducer) or contact ATI for assistance. Particular attention should be paid to dynamic loads caused by robot acceleration and deceleration. These forces can be many times the value of static forces in high acceleration or deceleration situations.

1.2 Explanation of Warnings

The warnings included here are specific to the product(s) covered by this manual. It is expected that the user heed all warnings from the robot manufacturer and/or the manufacturers of other components used in the installation.

Danger indicates that a situation could result in potentially serious injury or damage to equipment.

Caution indicates that a situation could result in damage to the product and/or the other system components.

1.3 Precautions

DANGER: Do not attempt to disassemble the transducer. This will damage the instrumentation.

DANGER: Do not probe any openings in the transducer. This will damage the instrumentation.

DANGER: Take care to prevent excessive forces or moments from being applied to the transducer during handling or installation. The small Nano series is easily overloaded during rough handling and may be damaged.

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2. Getting Started

2.1 Introduction

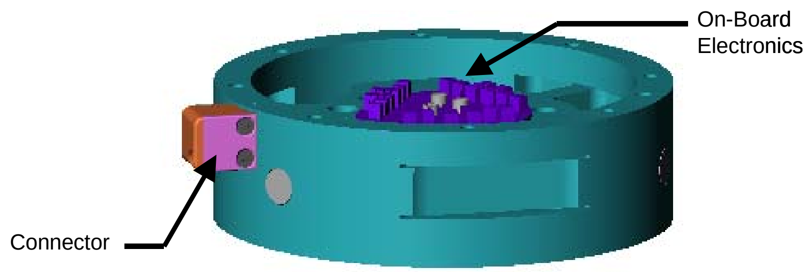
This section gives instructions for setting up the F/T system. Final installation is covered in *Section 3*. After setting up the system, a test is performed to check for problems. It is possible to start learning the commands described in *Section???* before starting the final installation.

⚠ **CAUTION:** The Force/Torque transducer, the calibration data loaded on the CD and the IFPS box, if applicable, have been assigned matching serial numbers when the system was calibrated. If these serial numbers assigned to your F/T system do not match, the force and torque outputs will be incorrect. Do not mix system components from different systems.

2.2 Unpacking

- Check the shipping container and components for damage due to shipping. Any damage should be reported to ATI Industrial Automation.
- Check the packing list for omissions.
- The following are standard components for an F/T system (If you will be using your own data acquisition system, you may not receive all the items.):
  - Transducer
  - Transducer cable (for 9105-TIF transducers)
  - Power Supply or Interface Power Supply Box
  - Power Supply cable
  - Data Acquisition Card and its CD – if ordered
  - ATI CD containing software, calibration documents, and manuals.
- The following are optional components:
  - Mounting ring-plug adaptor; replaces mounting adaptor on some models
  - Tool ring-plug adaptor; replaces tool adaptor on some models.

⚠ **CAUTION:** The transducer, Power Supply box, Interface Power Supply box, and DAQ card are susceptible to damage from electrostatic discharge whenever they are not connected to a plugged-in computer. Do not touch the electronics or the connector pins when handling the transducer.



2.3 System Components Description

2.3.1 Transducer

The transducer is a compact, rugged, monolithic structure that converts force and torque into analog strain gauge signals . The transducer is commonly used as a wrist sensor mounted between a robot and a robot end-effector. Factory-installed overload pins give Delta and Theta transducers extra protection from damage due to inadvertent overloads. *Figure 2.1* shows the transducer with a standard tool adaptor.

For further information not in this section see:

- *Section 3, Final Installation*, for mounting and cable routing.
- *9620-05-Transducer Section – Installation, Operation, and Specification Manual* for sepcifications (i.e.; resolution, weight) and mechanical drawings.

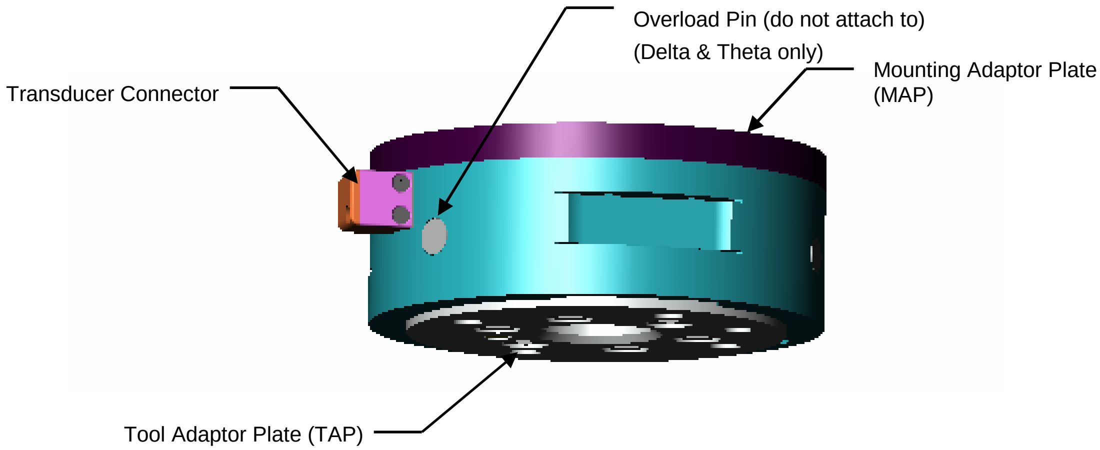


Figure 2.1—Transducer

> ***Aside:***
>
> The transducer is designed to withstand extremely high overloading through its use of strong materials and quality silicon strain gauges. Some models use a hardened stainless steel with twice the strength of titanium for overload protection while other transducers use mechanical overload pins to prevent damage.

2.3.2 Transducer Cable

The high-flex life transducer cable is electrically shielded to protect transmission from the transducer Power Supply or Interface Power Supply boxes, small transducers have the cable integrally attached. Larger transducers have a separate cable [See *Figure 2.2*].

For further information not in this section see:

- Section 3, Final Installation, for cable routing.

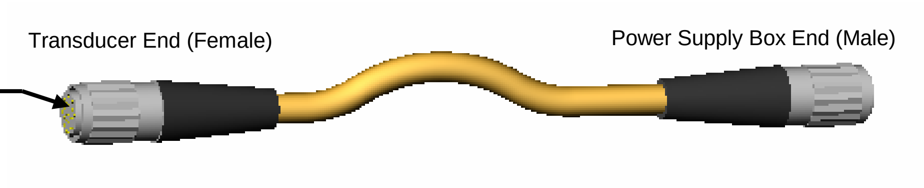


Figure 2.2a—Transducer Cable for 9105-TIF Transducers

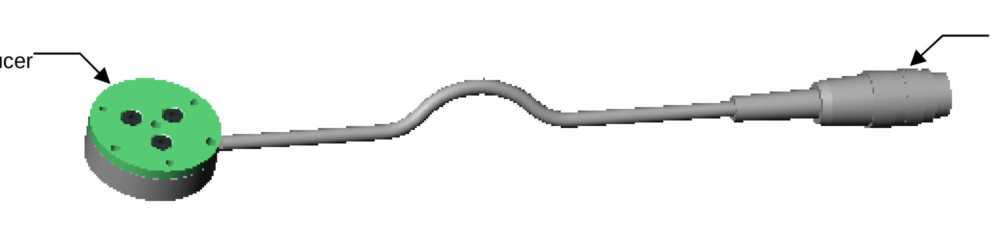


Figure 2.2b—Integral Transducer Cable on Small Transducers

2.3.3 Power Supply and Interface/Power Supply Boxes

The Interface Power Supply box is typically used with the small Nano and Mini transducers. It supplies power to the transducer and electronics as well as conditioning the transducer signals to be used with a data acquisition system. The transducer's 12-pin cable plugs into this box. The Power Supply box is used with larger transducers that have on board interface electronics. The 20-pin transducer cable plugs into this box.

2.3.4 Power Supply Cable

The robust power supply cable connects the Power Supply box or Interface Power Supply box to the data acquisition system. This cable usually has a connector on the data acquisition end, but is also available unterminated.

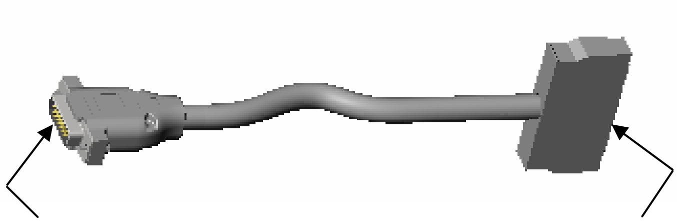


Figure 2.3—Power Supply Cable

2.3.5 Data Acquisition System

The data acquisition system converts the transducer signals from analog voltages into data your computer can use. This data is not the final force and torque values. The data acquisition system also supplies raw power to the transducer system.

2.3.6 F/T Software CD

The F/T software CD contains the software and calibration data that your computer uses to convert the transducer readings into usable force and torque output. It also has Microsoft Windows® drivers, sample programs, C source code, and detailed help files. The most recent release of the DAQ software can be found on the web at http://www.ati-ia.com/download/software.htm.

Aside:

The CD included with the DAQ system contains extensive help files on its software that will benefit both the beginner and the advanced user. The CD even includes a spreadsheet to help advanced users with calculations, see the *Advanced Techniques* section of the help file for more information.

2.3.7 Interface Plates

The larger transducers come with a standard mounting adaptor to mechanically attach the transducer to your robot arm or apparatus that will be applying the force. The transducer also has a standard tool adaptor with an ISO 9409-1interface for Gamma, Delta, and Theta models for attaching your tool.

The mounting adaptor consists of:

- Mounting adaptor plate
- Mounting screws

For further information not in this section see:

- *Section 3, Installation*
- *9620-05-Transducer Section – Installation, Operation, and Specification Manual* for sepcifications (i.e.; resolution, weight) and mechanical drawings.

2.4 Connecting the System Components

2.4.1 Connecting the Transducer Cable

Large DAQ F/T transducers connect to the system through a high-density 20-pin connector. (see *Figure 2.3*). The Nano and Mini F/Ts have integral cables.

Connect the transducer cable connector to the transducer as follows:

- Lightly place the connector into port on the transducer. Do not push.
- Line up the groove on the connector to the key in the port by rotating the connector while lightly forcing the connector into the port. When the groove lines up the connector will go noticeably deeper into the port.
- Screw the connector shell into the transducer until it seats firmly.

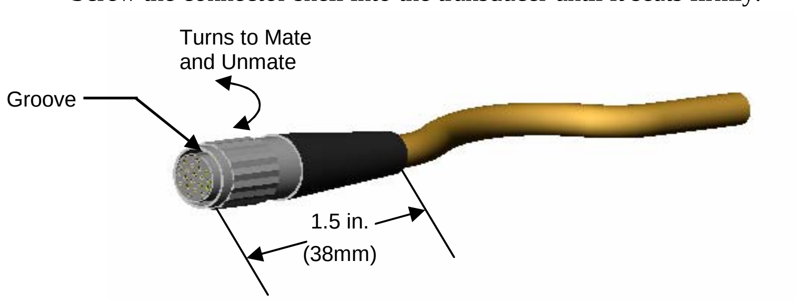


Figure 2.4—Transducer Connector

Disconnect the transducer connector from the transducer port by unscrewing the connector shell.

⚠ **CAUTION:** Cables on the Nano and Mini transducers are permanently attached to the transducer and can not be disconnected. Do not attempt to disassemble these transducers as **damage will occur**.

2.4.2 Installing the Data Acquisition Hardware

Install the data acquisition hardware and its accompanying software following the instructions included with the hardware.

2.4.3 Connecting to the Data Acquisition Hardware

If you are using a NI PCMCIA (a small PC card for laptop computers), you will need to attach the short adaptor cable to the card. The other end of the adaptor cable connects to the F/T Power Supply cable.

Connect the 26-pin D-subminiature connector side of the Power Supply cable to the Power Supply or Interface Power Supply box. Tighten the jackscrews on the connector to insure a good electrical connection.

Connect the 68-pin connector side of the Power Supply cable to the NI data acquisition hardware. Tighten the jackscrews on the connector to insure a good electrical connection. Please note that the PCMCIA adaptor does not use the jackscrews. In this case you must insure the connectors do not get pulled apart.

> ***Aside:***
>
> If you are not using a National Instruments E-Series DAQ board, you will have to provide your own connector at that end of the cable.

2.4.4 Testing with the ATI DAQ Demo on a Windows® Computer

Install the F/T software by inserting the CD in your computer. The installation program should start automatically. If it does not start automatically, you will need to run *SETUP.EXE* found in the root directory of the CD. Follow the installation instructions given by the program.

View the *README.TXT* file found in the root directory of the CD.

Copy your transducer's calibration file(s) from the CD directory *\Calibration* to the program directory *ATI DAQ FT* . Calibration file names are based on the transducer's serial number and is in the format of *FTxxxx.CAL.* There will be multiple calibration files if the system was ordered with more than one calibration.

Run the demo program found in the Start Menu under *Programs\ATI DAQ FT\ATI DAQ FT Demo.* In the program you must load the calibration data. Do this by clicking on the menu *File*, then *Open Calibration.* Find the calibration data file you saved earlier and click the *Open* button. At this point the program should be displaying two sets of bar graphs; one labeled *Force* and the other labeled *Torque.* The center bottom of the demo window will show the transducer model and calibration for the loaded calibration file.

Gently apply load to the transducer without over-ranging the transducer. You should see the bar graphs respond.

> ***Aside:***
>
> The ATI DAQ demo only works in conjunction with National Instruments DAQ boards.

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3. Installation

3.1 Introduction

Proper installation of your transducer, its cabling, IFPS or PS box, and data acquisition hardware is essential to proper operation.

3.2 Transducer and Cable Installation

See ATI Industrial Automation manual 9620-05-Transducer Section, *Transducer Installation, Operation, and Specification Manual* for installation information

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4. How It Works

4.1 Introduction

This section provides a functional outline of the F/T system. The F/T system is broken into three areas: electrical, controlling software, and mechanical. A mechanical description is shown in *Section 4.2*. A graphical representation of the electronics and software is presented in *Section 4.3*.

4.2 Mechanical Description

The property of forces was first stated by Newton in his third law of motion: *To every action there is always opposed an equal reaction; or, the mutual action of two bodies upon each other are always equal, and directed to contrary parts.* The transducer reacts to applied forces and torques using Newton's third law.

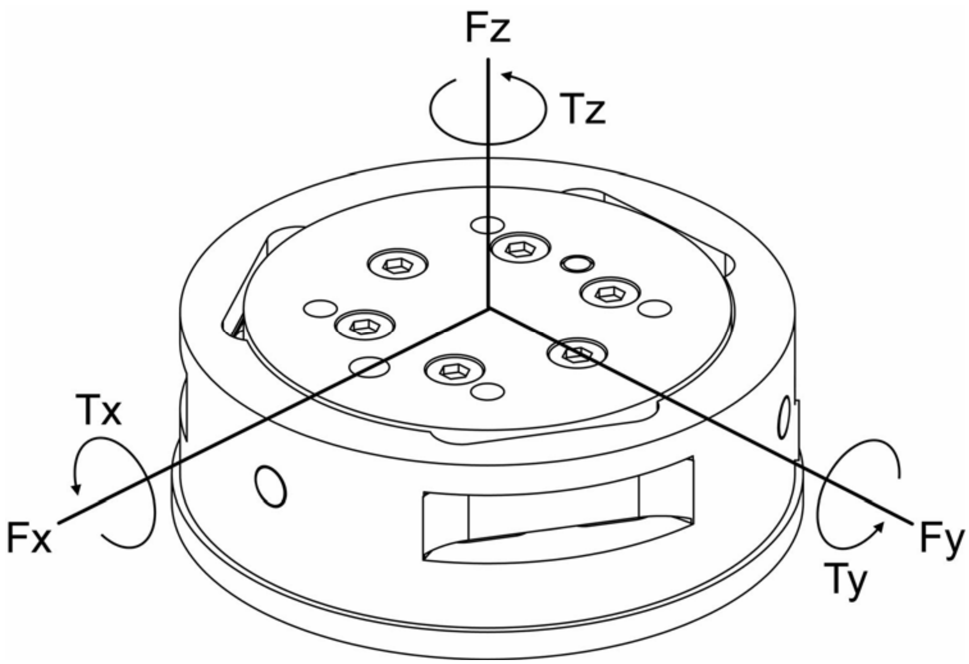

Figure 4.1—Applied force and torque vector on transducer

The force applied to the transducer flexes three symmetrically placed beams using Hooke's law:

σ	=	$E \cdot \varepsilon$
σ	=	Stress applied to the beam (σ is proportional to force)
E	=	Elasticity modulus of the beam
ε	=	Strain applied to the beam

> ***Aside:***
>
> The transducer is monolithic structure. The beams are machined from a solid piece of metal. This decreases hysteresis and increases the strength and repeatability of the structure.

Semiconductor strain gauges are attached to the beams and are considered strain-sensitive resistors. The resistance of the strain gauge changes as a function of the applied strain as follows:

ΔR	=	$S_a \cdot R_o \cdot \varepsilon$
ΔR	=	Change in resistance of strain gauge
S_a	=	Gauge factor of strain gauge
R_o	=	Resistance of strain gauge unstrained
ε	=	Strain applied to strain gauge

The electronic hardware, described in *Section 4.3*, measures the change in resistance and the software, described in *Section 5*, converts this change to force and torque components.

4.3 Electronic Hardware

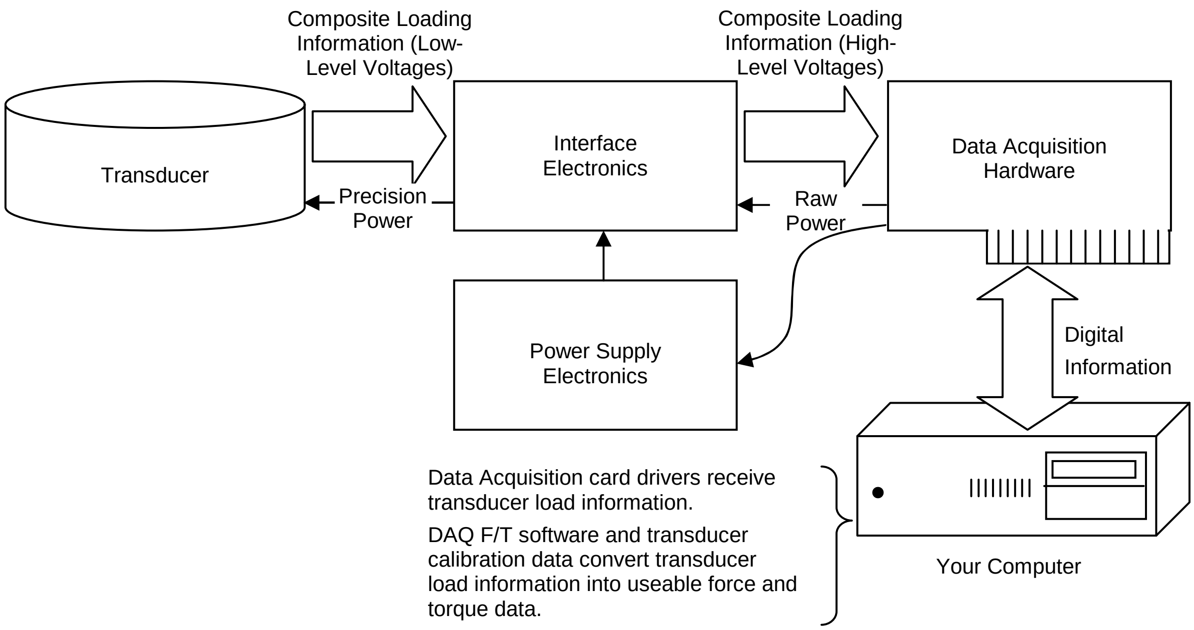

Figure 4.2—Electronic Hardware Outline

5. ATI DAQ Software

The computer that you connect your F/T system's data acquisition card to performs the important functions of converting the data acquisition card data into useful force and torque values and making these values available for use to you.

The ATI DAQ F/T Software CD contains reusable software components that you can use to build your application, as well as sample applications to get you started. (Unless otherwise noted, all Windows® components and applications support Windows® 95, 98, Me, NT, 2000, and XP.)

> ***Aside:***
>
> The ATI DAQ F/T software CD contains extensive documentation on its software. Check this documentation for detailed help. CD updates can be found at *http://www.ati-ia.com/download/DAQ_FT/DAQ%20FT%20Software.htm*.

5.1 Reusable Software Components

5.1.1 ATI DAQFT Automation Server

This Windows® ActiveX component reads calibration files, configures the transducer system, and converts raw voltages from any data acquisition system into forces and torques. ATIDAQFT can be used in development platforms that support ActiveX or Automation containment, including Microsoft Visual Basic 6.0, Microsoft Visual C++, Microsoft.NET Platform, National Instruments LabVIEW, and many others. Its programming API is documented in the ATIDAQFT help files.

5.1.2 C Library

This code library uses standard ANSI C to read calibration files, configure the transducer system, and convert voltage data from any data acquisition system into forces and torques.

5.2 Sample Applications

5.2.1 Windows® Demo (Visual Basic 6.0)

This executable program is a good place to try out your new transducer system in Windows®. It uses National Instruments-DAQ and ATIDAQFT to give a real-time display of F/T data from National Instruments E-Series Multifunction I/O devices. It provides complete options for configuration of the F/T system. Microsoft Visual Basic 6.0 source is included.

5.2.2 LabVIEW Sample

This is a demo application in LabVIEW using the ATIDAQFT Automation server and the Analog Input VIs provided by NI-DAQ. This sample application provides a real-time display of F/T data.

5.3 Designing Your DAQ F/T Application

Your DAQ F/T application must include at least two components:

5.3.1 Device Drivers for Your DAQ Device and Target Operating System

National Instruments includes several sets of Windows® device drivers with their data acquisition devices, including 32-bit DLLs, LabVIEW VIs, and ActiveX controls. Non-Windows® device drivers for National Instruments systems may be available from third-party sources. For other brands of data acquisition devices, device drivers must be obtained from the device manufacturer or a third-party source.

5.3.2 ATI DAQ F/T Components or C Library

This part of your application is used to load a calibration file, apply settings such as tool transformations, and convert raw voltages into forces and torques. For Windows® applications, the ATIDAQFT Automation server is recommended. The conversion to forces and torques can occur in real-time, or can be applied as a batch operation at the end of the acquisition operation.

6. Electrical Connection Information

This section contains detailed information about the electrical connections of the various F/T system components.

> ***Aside:***
>
> Information in this section is intended for advanced users. Users whose systems include an ATI-supplied DAQ card may skip this section.

The ATI DAQ F/T software features a modular design to allow you to use our system with any data acquisition system capable of electrically interfacing to the transducer.

Once you have obtained the digitized transducer data per your data acquisition card instructions, the data needs to be transformed into force and torque data using the drivers and instructions on the ATI DAQ F/T software CD.

6.1 Signals and Power

> ⚠ **CAUTION:** The analog signals output by the transducer do not map directly into force and torque vectors. ATI DAQ F/T software must be used to convert these values into force and torque data.

Signal Name	Description
SG*x* Output	The non-inverting (positive) half of output of SG*x*
SG*x* Reference	The inverting (negative) half of output of SG*x*
$+V_{ANA}$	Positive power supply used by transducer
AGnd	Power supply return used by transducer
$-V_{ANA}$	Negative power supply used by transducer
+5V	Positive power used by PS or IFPS box
0V	Power supply return used by PS or IFPS box
AIGnd	Analog Input Ground used for input current return from data acquisition card
Reserved	This connection has an internal or future use. Do not use.

Table 6.1—Signal Descriptions

Systems with an ATI supplied DAQ card have their power derived from the DAQ card. If you are using your own DAQ card, you will need to provide a +5V power and 0V power to the PS or IFPS box. Without a PS box you will need to supply $+V_{ANA}$, AGnd , and $-V_{ANA}$ power to the transducer. (This applies to 9105-TIF transducers only; 9105-TW transducers require their IFPS box.)

6.2 Electrical Specifications

6.2.1 PS and IFPS box with transducer attached.

Signal	Minimum	Typical	Maximum	Units
+5V Power Input Voltage	4.75	5.00	9.00	V DC
+5V Power Input Current		260		mA
+5V Power Input Noise			75	mV p-p
+5V Power Input Regulation			0.5%	

Table 6.2—PS and IFPS box with transducer attached

6.2.2 Transducer with Onboard Interface Board

Signal	Minimum	Typical	Maximum	Units
$+V_{ANA}$ Power Input Voltage	13.00	15.00	17.00	V DC
$-V_{ANA}$ Power Input Voltage	-17.00	-15.00	-13.00	V DC
$+V_{ANA}$ Power Input Current		16		mA
AGnd Power Input Current		25		mA
$-V_{ANA}$ Power Input Current		-41		mA
V_{ANA} Power Input Noise			75	mV p-p
V_{ANA} Power Input Regulation			0.5%	

Table 6.3—Transducer with Onboard Interface Board

6.2.3 Transducer Output Signals

These are output by the transducer and passed through the PS box or are output by the IFPS box.

Signal	Minimum	Maximum	Units
SG*x* output*	$-V_{ANA}$ +0.6	$+V_{ANA}$ –0.8	V
SG*x* reference	AGnd	AGnd	V
SG*x* output, over 10V calibrated range	-10	+10	V
SG*x* output, over 5V calibrated range	-5	+5	V

* These output levels only occur if the transducer is loaded significantly past its calibration range.

Table 6.4—Transducer Output Signals

The transducer outputs are designed to work with a differential input to the DAQ system for best performance.

The calibrated output voltage range is indicated as a suffix to the calibration. For example, a GAMMA transducer with SI-65-5 calibration and a +10V output voltage range would be expressed as a GAMMA/SI-65-5:10V. The output voltage range can also be read using the OutputRange property of the ATIDAQFT software component.

6.3 Transducer Signals

This section covers the connections for transducers with on-board electronics (9105-TIF part numbers). These transducers have a 20-pin connector. User connections to transducers without on-board electronics (9105-TW part numbers) are not supported and therefore not covered in this document.

The transducer connector mates to a Hirose HR25-9TP-20S connector. Wire colors are shown for use with 9105-C-H-U cable assemblies.

Note: Multi-colored wires are identified as follows: The first color listed is the predominant color of the wire and the second color is the stripe on the wire.

Pin	Description	Wire Colors
1	SG0 output	Brown
2	Reserved	Orange
3	SG0 reference	Brown/White
4	SG3 reference	Blue/White
5	SG5 reference	Grey/White
6	$+V_{ANA}$ power input	Red
7	SG1 output	Yellow
8	SG3 output	Blue
9	SG5 output	Grey
10	AGnd power input	Black

Pin	Description	Wire Colors
11	$-V_{ANA}$ power input	Red/White
12	SG1 reference	Yellow/White
13	SG4 output	Violet
14	Reserved	White
15	Reserved	Black/White
16	Reserved	Orange/White
17	SG2 output	Green
18	SG4 reference	Violet/White
19	Reserved	White/Black
20	SG2 reference	Green/White
Shell	Shielding	Shield

Table 6.5—Transducer connector connections and 9105-C-H-U cable wire colors

6.4 PS and IFPS Signals

6.4.1 PS 20-pin Circular Connector

These signals and pin numbering are the same as the transducer signals listed in Section 5.3. See Table 5.5.

6.4.2 PS and IFPS 26-pin High Density D-Subminiature Connector

This connector mates to an industry standard female 26-pin high-density D-subminiature connector with screw locks. Wire colors are shown for use with 9105-C-PS-U cable assemblies.

Pin	Description	Wire Colors
1	Reserved	Orange
2	+5V power input	Red
3	Reserved	White
4	SG5 output	Grey
5	SG4 output	Violet
6	SG3 output	Blue
7	SG2 output	Green
8	SG1 output	Yellow
9	SG0 output	Brown
10	Reserved	Orange/White

Pin	Description	Wire Colors
11	0V power input	Red/White
12	Reserved	White/Black
13	SG5 reference	Grey/White
14	SG4 reference	Violet/White
15	SG3 reference	Blue/White
16	SG2 reference	Green/White
17	SG1 reference	Yellow/White
18	SG0 reference	Brown/White
19	Reserved	Black/White
22	AIGnd	Black
Shell	Shielding	Shield

Table 6.6—PS box and IFPS box connector connections and 9105-C-PS-U cable wire colors

6.5 DAQ Card Connections

6.5.1 Standard DAQ Card Connections

Our standard DAQ card configuration is based on the National Instruments M-Series and E-Series 68-pin connections. Advanced users can use the following table to better understand the system connections. Unlisted connector pins are not used.

H	PS	NI	ATI Signal	(NI name)
	2	8	+5V power(+5V)	(+5V)
	11	13	0V power	(D Gnd)
6			$+V_{ANA}$ power	
10	22	56	AGnd/AIGnd	(AIGnd)
11			$-V_{ANA}$ power	
1	9	68	SG0 output	(AI 0)
3	18	34	SG0 reference	(AI 8)
7	8	33	SG1 output	(AI 1)
12	17	66	SG1 reference	(AI 9)
17	7	65	SG2 output	(AI 2)
20	16	31	SG2 reference	(AI 10)

H	PS	NI	ATI Signal	(NI name)
8	6	30	SG3 output	(AI 3)
4	15	63	SG3 reference	(AI 11)
13	5	28	SG4 output	(AI 4)
18	14	61	SG4 reference	(AI 12)
9	4	60	SG5 output	(AI 5)
5	13	26	SG5 reference	(AI 13)
14	3	25	reserved	(AI 6)
19	12	58	reserved	(AI 14)
2	1	57	reserved	(AI 7)
16	10	23	reserved	(AI 15)
15	19	52	reserved	(P0.0)

H = connectors between 9105-TIF transducer and PS box
PS = DAQ-side connector on PS and IFPS box
NI – DAQ connector or National Instruments E-Series and M-Series boards

Table 6.7—System Connections

6.5.2 Custom DAQ Card Connects

Advanced users may have purchased systems that use an unterminated power supply cable. The NI signal names listed in Table 6.7 may be used as a guide when connecting the unterminated cable to other National Instruments data acquisition equipment.

6.6 Using Unused DAQ Card Resources

There are additional functions available on the ATI-supplied DAQ card that are not used in the standard configuration. Information about using these resources is outside the scope of this manual. Users who wish to use these need to consult the DAQ card documentation for connections and functionality. Table 6.7 shows which signals are used by the F/T system and cannot be used for other purposes. Additional connections to the DAQ card can introduce ground loops and noise if not designed properly.

7. Advanced Topics

7.1 Data Collection Rates

Our DAQ F/T sensor systems are designed to be electrically compatible with most commercially available general-purpose and high-accuracy data acquisition hardware. For best performance in all applications, the transducer electronics do not filter the outputs. This allows collection of all transducer frequency content. Please note that to satisfy the Nyquist Theorem†, the data needs to be coupled at a rate that is greater than twice the highest frequency present, even if you are not interested in data at that frequency.

Please note that significant error can be introduced in the transducer data if a National Instruments E-Series card is sampling each data set at over 40 kHz (240 kHz per channel). Users with fast NI-DAQ devices should not use the single-scan functions of NI-DAQ, such as AI_Read_Scan and AI-VRead_Scan. A buffered operation (such as Scan_Op) should be used instead. In the demo, *ATI DAQ FT Demo*, the *Buffer Mode* option should be enabled.

† The Nyquist Theorem applies to data collection and states that data acquired must be collected at a data rate greater than twice the highest frequency present in the data, otherwise the data will be erroneous. The theorem was developed by Henry Nyquist as he sought to improve communications systems in the first part of the twentieth century.

7.2 Detecting Failures (Diagnostics)

7.2.1 Detecting Connection Issues

The F/T system is designed to output voltages that are within the specified output voltage range (±5V or ±10V) as long as the transducer is not being overloaded and the transducer is connected to the PS or IFPS box. If the transducer cable is disconnected or has been damaged, the output of the system will be outside the specified output voltage range. By performing periodic checks of the voltages, a failure can be detected. If any of the voltages are at or outside this range, there may be a problem with the transducer or its cabling.

⚠ **CAUTION:** When any strain gage output is saturated or otherwise inoperable, **all transducer F/T readings are invalid.** Therefore, if is vitally important to monitor for these conditions.

7.2.2 Detecting Cable Problems

A properly functioning DAQ system will deliver voltages from the transducer to the DAQ card inputs that represent the transducer loading. The DAQ system provides two safety features to aid in detection of cabling problems that could disrupt the reading of transducer voltages.

1. If the cable is disconnected between the transducer and its IFPS or PS box, then voltages sent to the DAQ card from the box will be forced to a saturation level.
2. The seventh output channel outputs a voltage that is either -1.54V if no temperature reader circuit is installed or a voltage that is greater than +0.5V if the temperature reader is installed and the temperature is above -10^{o}C.

If the acquired transducer voltages are A/D saturated or the seventh channel is not between -1.6V to -1.5V or not between +0.5V and saturation, then there may be a cable issue.

7.2.3 Detecting Sensitivity Changes

Sensitivity checking of the transducer can also be used to measure the transducer system's health. This can be done by applying known loads to the transducer and verifying the system output matches the known loads.

For example, a transducer mounted to a robot arm may have an end-effector attached to it:

1. If the end-effector has moving parts, they must be moved in a known position,
2. Place the robot arm in an orientation that allows the gravity load from the end-effector to exert load on many transducer output axes.
3. Record the output readings.
4. Position the robot arm to apply another load, this time causing the outputs to move far from the earlier readings.
5. Record the second set of output readings.
6. Find the differences from the first and second set of readings and use it as your sensitivity value.

Even if the values vary somewhat from sample set to sample set, they can be used to detect gross errors. Either the resolved outputs or the raw transducer voltages may be used (the same must be used for all steps of this process).

7.3 Scheduled Maintenance

7.3.1 Periodic Inspection

For most applications there are no parts that need to be replaced during normal operation. With industrial-type applications that continuously or frequently move the system's cabling you should periodically check the cable jacket for signs of wear. These applications should implement the procedures discussed in *Section 7.2—Detecting Failures (Diagnostics)* to detect any failures.

The transducer must be kept free of excessive dust, debris, or moisture. Applications with metallic debris (i.e., electrically-conductive) must protect the transducer from this debris. Transducers without specific factory-installed protection are to be considered unprotected. The internal structure of the transducers can become clogged with particles and will become uncalibrated or even damaged.

7.3.2 Periodic Calibration

Periodic calibration of the transducer and DAQ card is required to maintain traceability to national standards. Follow any applicable ISO-9000-type standards for calibration. ATI Industrial Automation recommends annual recalibrations, especially for applications that frequently cycle the loads applied to the transducer.

7.4 A Word about Resolution

ATI's transducers have a three sensing beam configuration, where the three beams are equally spaced around a central hub and attached to the outside wall of the transducer. This design transfers applied loads to multiple sensing beams and allows the transducer to increase its sensing range in a given axis if a counterpart axis has reduced loading (see *9620-05-Transducer Installation, Operation, and Specification Manual* for compound loading information).

The resolution of each transducer axis depends on how the applied load is spread among the sensing beams. The best resolution occurs in the scenario when the quantization of the gauges is evenly distributed as load is applied. In the worst case scenario, the discrete valve of all involved gauges increases at the same time. The typical scenario will be somewhere in between these two.

F/T resolutions are specified as *typical resolution*, defined as the average of the worst and best case scenarios. Because both multi-gauge effects can be modeled as a normal distribution, this value represents the most commonly perceived, average resolution. The

DAQ F/T resolutions are based on real-number calculations and do not result in clean fractions. To express the values as clean fractions, we simply use the values that a 16-bit DAQ card could achieve. Although this misrepresents the actual performance of the transducers, it results in a close (and always conservative) estimate.

7.5 Environmental

The standard F/T system is designed to be used in standard laboratory or light-manufacturing conditions. Transducers with an IP65 designation are able to withstand dusty environments, as well as wash down.

	Storage	Operation	Units
9105-TIF Transducer	-5 to 75	0 to 60	^oC
9105-TW Transducer	-5 to 120	-5 to 120	^oC
PS box	-30 to 75	0 to 60	^oC
IFPS box	-30 to 75	0 to 60	^oC

Note: These temperature ranges specify the storage and operation ranges in which the transducer can survive without damage. They do not take accuracy into account.

Table 7.1—Transducer Temperature Ranges

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8. Troubleshooting

8.1 Introduction

This section includes answers to some issues that might arise when setting up and using the F/T system. The question or problem is listed followed by the probable answer or solution and are categorized for easy reference.

The information in this section should answer many questions that might arise in the field. Customer service is available to users who have problems or questions not addressed in the manuals:

ATI Industrial Automation
Customer Service
Pinnacle Park
1031 Goodworth Drive
Apex, NC 27539 USA

Phone: +1.919.772.0115
Fax: +1.919.772.8259
E-mail: ft_support@ati-ia.com

Note:

Please read the F/T manuals before calling customer service. When calling, have the following information available:

1. Serial number(s)
2. Transducer type, e.g. Nano-17, Gamma, Theta
3. Calibration, e.g. US-15-50, SI-130-10
4. An accurate and complete description of the question or problem.
5. Controller revision. This is output in the initialization header message of the Controller.

If possible, the F/T system should be accessible when talking with an ATI Industrial Automation customer service representative.

8.2 Questions and Answers

8.2.1 Errors with force and torque readings

Bad data from the transducer's strain gauges can cause errors in force/torque readings. These errors can result in problems with threshold monitoring, sensor biasing and accuracy. Listed below are the basic conditions of bad data. Use this to troubleshoot your problem. In most cases, problems can be seen better while viewing raw strain gauge data.

Question/Problem:	Answer/Solution:
Saturation	When the data from a raw decimal strain gauge reads the positive or negative maximums, that gauge is saturated. Saturation occurs if the sensor is loaded beyond its rated maximum or in the event of an electrical failure within the system.
Noise	Excessive noise can be caused by mechanical vibrations and electrical disturbances, possibly from a poor ground. It can also indicate component failure within the system.
Drift	After a load is removed or applied, the raw gauge reading does not stabilize but continues to increase or decrease. This may be observed more easily while viewing resolved F/T data. Drift is caused by temperature change, mechanical coupling, or internal failure. Mechanical coupling is caused when a physical connection is made between the tool plate and the sensor body (i.e., plastic filings between the tool adapter plate and the transducer body). Some mechanical coupling is common, such as hoses and wires attached to a tool.
Hysteresis	When the sensor is loaded and then unloaded, gauge readings do not return quickly and completely to their original readings. Hysteresis is caused by mechanical coupling (explained in drift section) or internal failure.

9. Terms and Conditions of Sale

The following Terms and Conditions are a supplement to and include a portion of ATI's Standard Terms and Conditions, which are on file at ATI and available upon request.

ATI warrants to Purchaser that force torque sensor products purchased hereunder will be free from defects in material and workmanship under normal use for a period of one year from the date of shipment. This warranty does not cover components subject to wear and tear under normal usage or those requiring periodic replacement. ATI will have no liability under this warranty unless: (a) ATI is given written notice of the claimed defect and a description thereof within thirty (30) days after Purchaser discovers the defect and in any event not later than the last day of the warranty period; and (b) the defective item is received by ATI not later ten (10) days after the last day of the warranty period. ATI's entire liability and Purchaser's sole remedy under this warranty is limited to repair or replacement, at ATI's election, of the defective part or item or, at ATI's election, refund of the price paid for the item. The foregoing warranty does not apply to any defect or failure resulting from improper installation, operation, maintenance or repair by anyone other than ATI.

ATI will in no event be liable for incidental, consequential or special damages of any kind, even if ATI has been advised of the possibility of such damages. ATI's aggregate liability will in no event exceed the amount paid by purchaser for the item which is the subject of claim or dispute. ATI will have no liability of any kind for failure of any equipment or other items not supplied by ATI.

No action against ATI, regardless of form, arising out of or in any way connected with products or services supplied hereunder may be brought more than one year after the cause of action accrued.

No representation or agreement varying or extending the warranty and limitation of remedy provisions contained herein is authorized by ATI, and may not be relied upon as having been authorized by ATI, unless in writing and signed by an executive officer of ATI.

Unless otherwise agreed in writing by ATI, all designs, drawings, data, inventions, software and other technology made or developed by ATI in the course of providing products and services hereunder, and all rights therein under any patent, copyright or other law protecting intellectual property, shall be and remain ATI's property. The sale of products or services hereunder does not convey any express or implied license under any patent, copyright or other intellectual property right owned or controlled by ATI, whether relating to the products sold or any other matter, except for the license expressly granted below.

In the course of supplying products and services hereunder, ATI may provide or disclose to Purchaser confidential and proprietary information of ATI relating to the design, operation or other aspects of ATI's products. As between ATI and Purchaser, ownership of such information, including without limitation any computer software provided to Purchaser by ATI, shall remain in ATI and such information is licensed to Purchaser only for Purchaser's use in operating the products supplied by ATI hereunder in Purchaser's internal business operations.

Without ATI's prior written permission, Purchaser will not use such information for any other purpose or provide or otherwise make such information available to any third party. Purchaser agrees to take all reasonable precautions to prevent any unauthorized use or disclosure of such information.

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F/T **Transducer**

Six-Axis

Force/Torque Transducer

Installation and Operation Manual

Manual #: 9620-05-Transducer Section

March 2008

Engineered Products for Robotic Productivity

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Forward

FCC Compliance - Class A

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

CE Conformity CE

CTL Transducers

This device complies with EMC Directive 89/336/EEC and conforms to the following standards: EN50081-1:1992, EN50082-1:1992, CISPR 22:1993 (EN55022:1994), IEC 1000-4-2:1995, IEC 1000-4-3:1995, IEC 1000-4-4:1995

DAQ Transducers

This device complies with EMC Directive 89/336/EEC and conforms to the following standards: EN55011:1998, ANSI C63.4:1992, EN61000-4-2:1995, EN61000-4-3:1995, EN61000-4-4:1995, EN61000-4-6:1995.

TWE Transducers

This device complies with EMC Directive 89/336/EEC and conforms to the following standards: EN50081-1:1992, EN50082-1:1992, CISPR 22:1993 (EN55022:1994), IEC 1000-4-2:1995, IEC 1000-4-3:1995, IEC 1000-4-4:1995

Aside

Please read the manual before calling customer service. Before calling, have the following information available:

1. Serial number (e.g.; FT01234)
2. Transducer model (e.g.; Nano17, Gamma, Theta, etc.)
3. Calibration (e.g.; US-15-50/S, SI-65-6/S, etc.)
4. Accurate and complete description of the question or problem
5. Computer and software information. Operating system, PC type, drivers, application software and other relevant information about your configuration.

If possible, have access to the F/T system when calling.

How to Reach Us

Sales, Service and Information about ATI products:

ATI Industrial Automation
1031 Goodworth Drive
Apex, NC 27539 USA
www.ati-ia.com

Tel: +1.919.772.0115
Fax: +1.919.772.8259
E-mail: info@ati-ia.com

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Application Engineering
Tel: +1.919.772.0115, Option 2, Option 2
Fax: +1.919.772.8259
E-mail: ft_support@ati-ia.com

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Glossary of Terms

Terms	Conditions
Accuracy	See *Measurement Uncertainty*.
Compound Loading	Any load that is not purely in one axis.
CTL	Denotes transducers and systems that use the F/T Controller interface.
DAQ	Denotes transducers and systems that use the data acquisition interface.
FS	**F**ull-**S**cale.
F/T	**F**orce and **T**orque.
Fxy	The resultant force vector comprised of components Fx and Fy.
Hysteresis	A source of measurement caused by the residual effects of previously applied loads.
IFPS	**I**nter**F**ace/**P**ower **S**upply box.
IP60	Ingress Protection rating 60 designates protection against dust.
IP65	Ingress Protection rating 65 designates protection against water spray.
IP68	Ingress Protection rating 68 designates submergibility in fresh water, in this case to a depth of 10 meters.
LabVIEW	A graphical programming environment created for data acquisition tasks by National Instruments.
Maximum Single-Axis Overload	The largest amount of pure load (not compound loading) that the transducer can withstand without damage.
MAP	**M**ounting **A**dapter **P**late. The transducer plate that attaches to the fixed surface or robot arm.
Measurement Uncertainty	The maximum expected error in measurements, as specified on the calibration certificate.
Mux Box	The component that contains transducer electronics for transducers that are too small to house them.
NI	**N**ational **I**nstruments Corporation, the owner of the *National Instruments* and *LabVIEW* trademarks. (www.ni.com)
Overload	The condition where more load is applied to the transducer than it can measure. This will result in saturation.
PC Card	A small computer card for use in most laptop computers.
PCMCIA Card	See *PC Card*. (*PCMCIA* has been renamed *PC Card* by its standards organization).
Point of Origin	The point on the transducer from which all forces and torques are measured.
PS	**P**ower **S**upply box.
Quantization	The process of converting a continuously variable transducer signal into discrete digital values. Usually used when describing the change from one digital value to the next.
Resolution	The smallest change in load that can be measured. This is usually much smaller than accuracy.
Saturation	The condition where the transducer or data acquisition hardware has a load or signal outside of its sensing range.
Sensor System	The entire assembly consisting of parts from transducer to controller.
TAP	**T**ool **A**dapter **P**late. The transducer surface that attaches to the load to be measured.
TWE	Denotes transducers that require user-amplification and data acquisition.
Tool Transformation	A method of mathematically shifting the measurement coordinate system resulting in a translated origin and/or rotated axes.
Transducer	The component that converts the sensed load into electrical signals.
Txy	The resultant torque vector comprised of components Tx and Ty.
Visual Basic	A Microsoft programming environment for developing Windows®-based applications.

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1. Safety

1.1 General

The customer should verify that the transducer selected is rated for the maximum loads and moments expected during operation. Refer to transducer specifications in Section 4 of this manual or contact ATI for assistance. Particular attention should be paid to dynamic loads caused by robot acceleration and deceleration. These forces can be many times the value of static forces in high acceleration or deceleration situations.

1.2 Explanation of Warnings

The warnings included here are specific to the product(s) covered by this manual. It is expected that the user heed all warnings from the robot manufacturer and/or the manufacturers of other components used in the installation.

Danger indicates that a situation could result in potentially serious injury or damage to equipment.

⚠ Caution indicates that a situation could result in damage to the product and/or the other system components.

1.3 Precautions

DANGER: Do not attempt to disassemble the transducer. This will damage the instrumentation.

DANGER: Do not probe any openings in the transducer. This will damage the instrumentation.

DANGER: Take care to prevent excessive forces or moments from being applied to the transducer during handling or installation. The small Nano series is easily overloaded during rough handling and may be damaged.

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2. Installation

2.1 Introduction

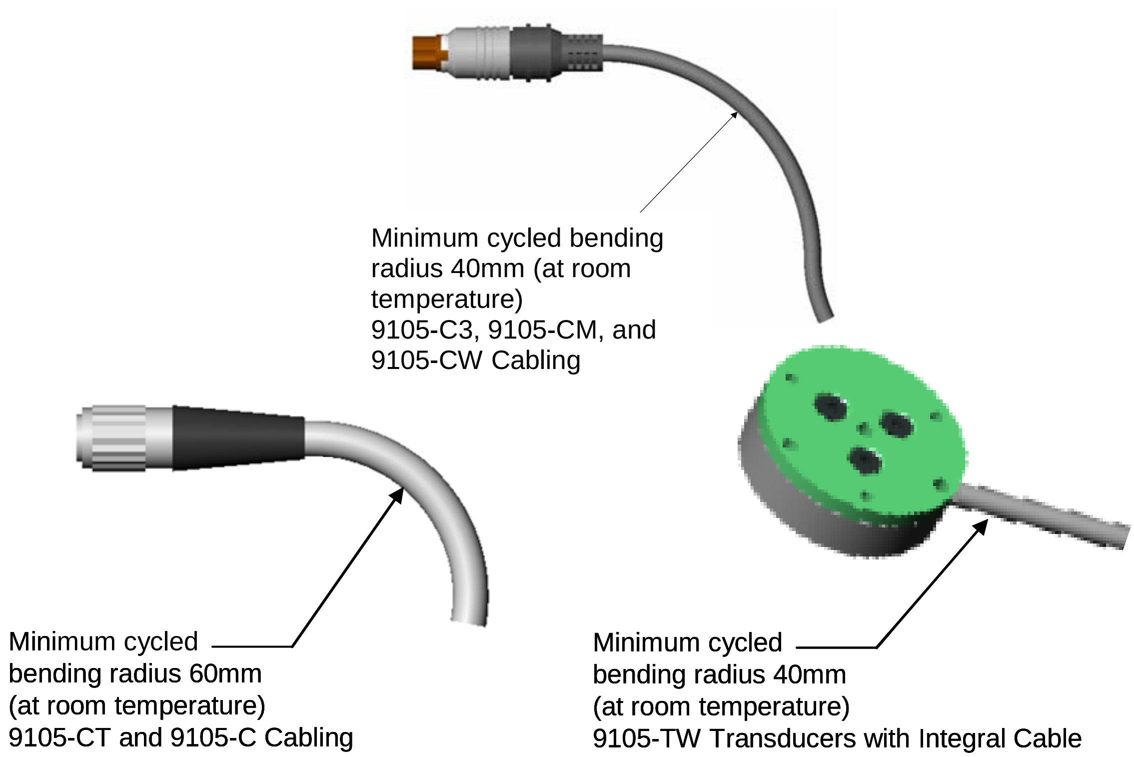
This section will assist the user in mounting the transducer, your tool, and the transducer cable.

2.2 Routing the Transducer Cable

The transducer cable must be routed so that it is not stressed, pulled, kinked, cut, or otherwise damaged throughout the full range of motion. See the accompanying system manual for the transducer cable interfacing. If the desired application results in the cable rubbing, then use a **loose** plastic spiral wrap for protection.

CAUTION: When the cable is cycling below the minimum bending radius, the cable may fail due to fatigue. A smaller radius can be used if it is not being cycled.

The minimum cycled bending radius is different with significant temperature changes, increasing with lower temperature and decreasing for higher temperature.



CAUTION: Do not stress or over bend the transducer cable, especially where it is attached to the transducer. This is particularly important on the Nano and Mini series of transducers. For these transducers, do not bend the cable any closer than 25mm (1 inch) to the transducer. Sharp bends must be avoided as they can damage the cable and transducer and will void the warranty.

CAUTION: Be careful not to crush the cable by over-tightening tie wraps or walking on the cable, since this may damage the cable.

⚠ **CAUTION:**

- Cables on the Nano and Mini transducers are permanently attached to the transducer and cannot be disconnected. Do not attempt to disassemble these transducers as damage will occur.
- Larger transducers have removable cables. Do not attempt to disconnect these transducer cables by pulling on the cable itself or the connector boot; this can damage your system.

⚠ **CAUTION:** Nano and Mini integral cables and cables of the 9105-C-H type must not subject the transducer end connection to more than 10 lbf (45 N) of side-to-side or pull force or permanent damage will result.

2.3 Transducer Environment

To ensure proper operation, the IP rating of the transducer must match or exceed the transducer's environment. Unless otherwise specified, a transducer has no special IP protection. In this case, the transducer may be used only in benign environments with no dust or debris and no liquids or spray.

⚠ **CAUTION:** Transducers without an IP protection may exhibit a small offset in readings when exposed to strong light.

⚠ **CAUTION:** Transducers may react to exceptionally strong and changing electro-magnetic fields, such as those produced by magnetic resonance (MRI) imaging machines.

Section 2.1 contains information on the transducer's temperature performance.

2.4 Mounting the Transducer

There are three different methods, I, II, and III, for mounting most F/T transducers. Mount the transducer to a structure with sufficient mechanical strength. Not doing so can lead to sub-optimum performance. **The Nano, Mini, Omega, and IP-rated transducers have mounting and tool adapters which cannot be removed, so only Method III can be used.** A detailed description of each method is given on the following pages and a brief description is given below.

2.4.1 Transducer Mounting Method I, Standard Adapter (summary)

Mounting Method I uses the standard mounting adapter to attach the transducer. This method is only available for transducers with customer-removable mounting adapter plates. You must machine the bolt pattern of your device (i.e.; robot) into the transducer's mounting adapter plate. You will not be able to use the mounting adapter alone if your device covers the mounting screws used to connect the transducer. If this is the case, use either Method II or Method III instead.

2.4.2 Transducer Mounting Method II, Ring-Plug Adapter (summary)

Mounting Method II uses the optional mounting ring-plug adapter as a replacement for the standard mounting adapter. You must machine the mounting plug to attach to your device. The mounting ring-plug adapter has the benefit of allowing the transducer to be connected and disconnected by hand (disconnecting may require a strap wrench). If the bolt pattern on your device can fit on the plug and you have access to the ring, then the mounting ring-plug adapter will work. If the bolt pattern is larger than the plug, use Method III.

2.4.3 Transducer Mounting Method III, User-Designed Interface (summary)

Mounting Method III uses your own interface plate to bolt directly to the transducer or (for the Nano, Mini, or Omega models) the mounting adapter.

The *Section 4—Transducer Specifications* contains detailed mechanical drawings of the transducer and all interface plates. Detailed descriptions of each method are shown on the next two pages.

> ***Aside:***
>
> Examine the sensor frame and cable routing section before modifying the mounting adapter plates. The F/T system's default sensor frame sets the tranducer's point-of-origin at the center of the mounting adapter's surface. See *Section 4—Transducer Specifications*, for drawings showing the default point of origin.

2.4.4 Transducer Mounting Method I, Standard Adapter

Use the mounting adapter to attach the transducer as follows:

- Ensure that you provide sufficient clearances between the mounted transducer and other fixtures and that total stack height is acceptable. Also check that after the mounting adapter is attached to the robot (or other device) you will have access to the mounting screws for attaching the transducer.
- Machine the mounting adapter plate for attaching to your robot (or other device) (see *Figure 2.1*). Mounting adapter plate dimensions are shown with the transducer in *Section 4—Transducer Specifications*. **All user-supplied screws must be flush with the inside of the mounting adapter to ensure proper clearance for the electronics inside the transducer.**
- Attach the mounting adapter to the robot (or other device). Attach the transducer to the mounting adapter with the screws and dowel pin provided. Thread locker is recommended to prevent the screws from backing out due to vibration (e.g.; Loctite thread locker No. 222).

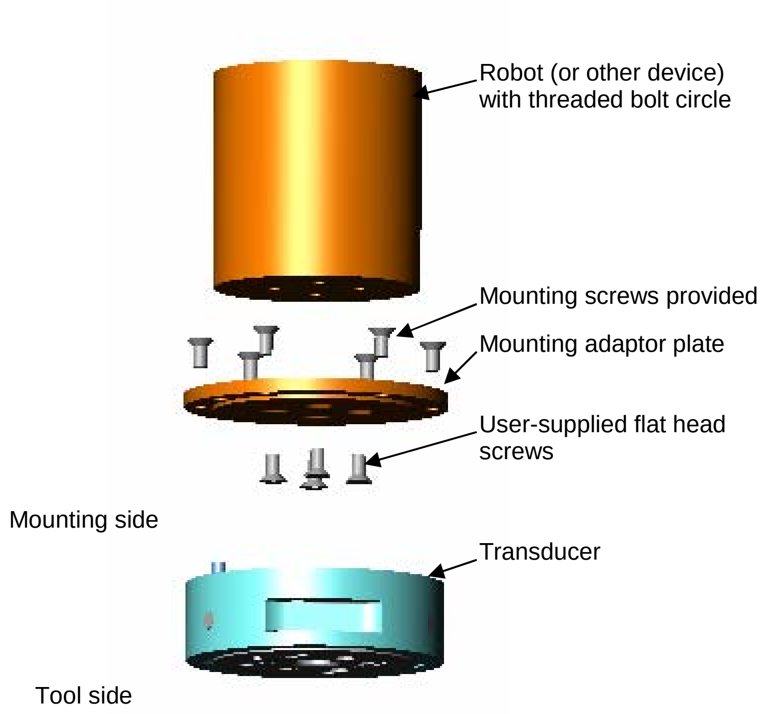


Figure 2.1—Attaching the transducer with the mounting adapter

2.4.5 Transducer Mounting Method II, Ring-plug Adapter

- Ensure that you provide sufficient clearances between the mounted transducer and other fixtures and that total stack height is acceptable. Also check that you will have room for tightening the mounting ring
- Machine the mounting plug for attaching to your robot (or other device). Mounting plug dimensions are shown with the transducer in *Section 4—Transducer Specifications* (see *Figure 2.2)*.
- Attach the mounting plug. Then attach the transducer to the mounting plug using the attached mounting ring and flange.

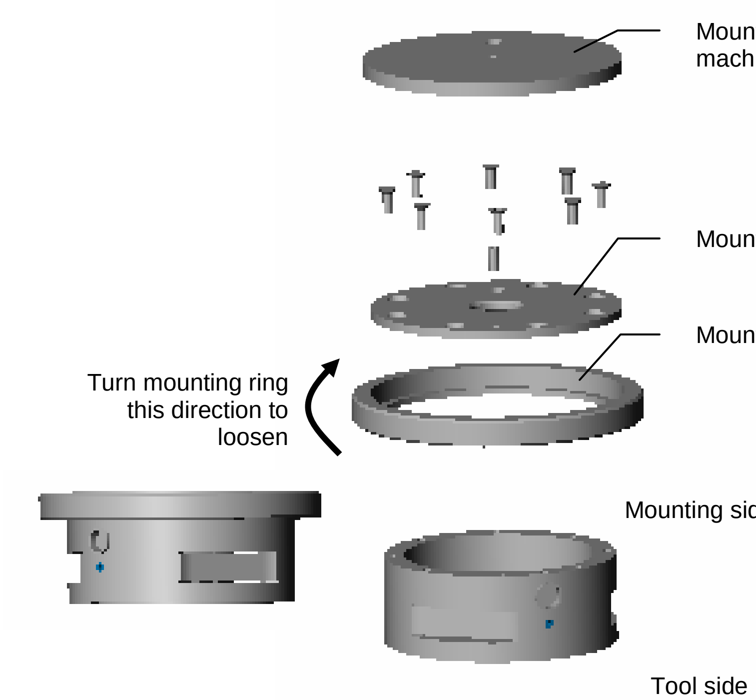


Figure 2.2—Using the mounting ring-plug adapter

> ***Aside:***
>
> How the ring/plug adapter works: The flange plate is held to the transducer with screws and dowel pins. The plug mates to the flange plate with a center boss and a dowel pin. The plug also mates to the ring with matching threads. When the ring is turned, the plug screws into the ring causing the plug to clamp to the flange plate.

> ***Aside:***
>
> If the ring cannot be removed by hand, use a strap wrench to loosen it. A strap wrench can be purchased through a supply company such as McMaster-Carr (PN-5378A1).

2.4.6 Transducer Mounting Method III, User-designed Interface

The transducer can be mounted using the bolt pattern provided. See *Section 4—Transducer Specifications*.

⚠ **CAUTION:** Do not attempt to drill, tap, machine, or otherwise modify or disassemble the transducer. This could damage the transducer and will void the warranty. Some transducers have removable plates that may be modified if removed. See drawings in *Section 4—Transducer Specifications* for details.

Aside:

Examine the cable routing (Section 2) before modifying the mounting adapter plates. The F/T System's default point-of-origin is at the center of the mounting adapter surface. See *Section 4—Transducer Specifications* for drawings showing the default point-of-origin.

2.5 Mounting Your Tool

There are two methods for mounting your tool to most F/T transducers. Method II is only available on the Gamma and Delta transducers. The two methods are described below.

2.5.1 Tool Mounting Method I, Standard Tool Adapter

The tool adapter is factory-installed and the bolt circle is shown with the transducer in *Section 4—Transducer Specifications.* Most F/T tool adapters follow the ISO 9409-1 mounting pattern. Machine your tool interface plate to attach to this bolt circle.

2.5.2 Tool Mounting Method II, Optional Tool Ring-plug Adapter

- This method is similar to the optional mounting ring-plug adapter. See *Section 2.4.5—Transducer Mounting Method II, Mounting Ring-plug Adapter* for details.
- Ensure that you provide sufficient clearances between the mounted transducer and other fixtures and that total stack height is acceptable. Also ensure that you will have room for tightening the tool ring
- Machine the tool plug for mounting to the end-effector. The dimensions of the tool plug are shown in *Figure 2.3*.
- Mount the tool plug to your tool. Then mount the transducer to the tool plug using the attached tool ring and tool flange. See the *Aside* notes in *Section 2.4.5* for how the ring-plug adapter works. The tool flange is not attached to the standard tool adapter, but replaces it.

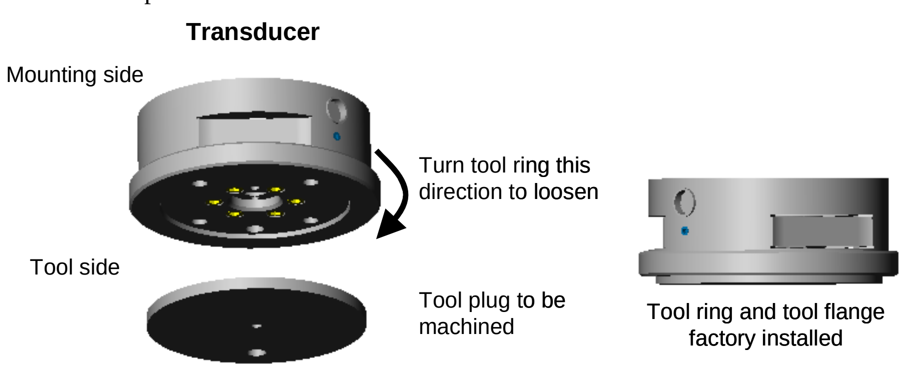


Figure 2.3—Using the tool ring-plug adapter

⚠ **CAUTION:** Your tool may only touch the tool adapter plate. If your tool touches any other part of the transducer it will not properly sense loads.

3. Topics

3.1 Accuracy Over Temperature

Typical gain errors introduced over temperature for F/T transducers with hardware temperature compensation are listed below. These changes in sensitivity are independent of the transducer's rated accuracy at room temperature; the two accuracy ratings must be added to find an overall estimated accuracy at a certain temperature. This overall accuracy assumes that the unloaded and loaded measurements were taken at the same temperature. Drift error over temperature is not compensated and varies with each transducer. For best results, a reference reading should be taken or bias function executed at the current temperature before applying the load of interest.

Deviation from 22°C	Typical Gain Error
± 5°C	0.1%
± 15°C	0.5%
± 25°C	1%
± 50°C	5%

Table 3.1—Error Introduced Over Temperature for Non-Gamma Transducers

Deviation from 22°C	Typical Gain Error
± 5°C	0.1%
± 15°C	0.5%
± 25°C	1.5%
± 50°C	7%

Table 3.2—Error Introduced Over Temperature for Gamma Transducers

3.2 Tool Transformation Effects

All transducer working specifications pertain to the factory point-of-origin only. This includes the transducer's range, resolution, and accuracy. The transducer working specifications at a customer-applied point-of-origin will differ from those at the factory point-of-origin.

3.3 Environmental

The F/T system is designed to be used in standard laboratory or light-manufacturing conditions. Transducers with an IP60 designation are able to withstand dusty environments, those with an IP65 designation are able to withstand dusty environments and wash down, and those with an IP68 designation are able to withstand dusty environments and fresh-water immersion to a specified depth.

Transducer Model Series	Storage	Operation	Units
9105-TIF Transducer	-5 to +75	0 to +60	°C
9105-TW Transducer	-5 to +120	-5 to +120	°C
9105-T Transducer	-5 to +120	0 to +70	°C

Note: These temperature ranges specify the storage and operation ranges in which the transducer can survive without damage. They do not take accuracy into account.

Table 3.3—Transducer Temperature Ranges

3.4 Mux Transducer Input Filter Frequency Response

Note: Mux transducers are only used in 9105-CTL, 9105-CON, and 9105-CTE systems.

The input filter used in 9105-T transducers and in the Mux box is used to prevent aliasing. This filtering is not used in 9105-TIF (DAQ) or our TWE transducers.

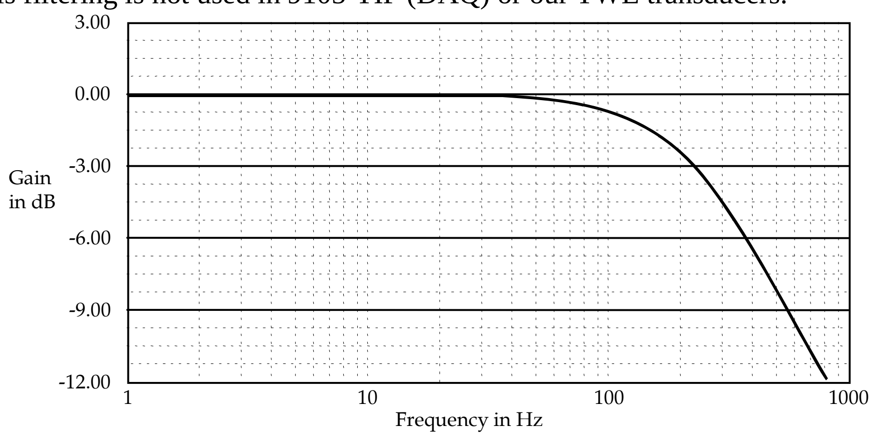


Figure 3.1—Mux input filter frequency response (-3dB @ 235Hz)

3.5 Transducer Strain Gauge Saturation

The F/T sensor's strain gauges are optimally placed to share information between the forces and torques applied to the sensor. Because of this sharing, it is possible to saturate the transducer with a complex load that has components below the rated load of the sensor. However, this arrangement allows a greater sensing range and resolution.

⚠ **CAUTION:** When any strain gauge is saturated or otherwise inoperable, **all transducer F/T readings are invalid**. Therefore, it is vitally important to monitor for these conditions.

The graphs in the sections for each transducer may be used to estimate a sensor's range under complex loading. Each page represents one sensor body with either English or Metric units. The top graph represents combinations of forces in the X and/or Y directions with torques about the Z-axis. The bottom graph represents combinations of Z-axis forces with X- and/or Y-axis torques. The graphs contain several different calibrations, distinguished by line weight.

The sample graph shown in Figure 3.2 shows how operating ranges can change with complex loading. The labels indicate the following regions:

A. Normal operating region. You can expect to achieve rated accuracy in this region.
B. Saturation region. Any load in this region will report a gauge saturation condition.
C. Extended operating region. In this region, the sensor will operate correctly, but the full-scale accuracy is not guaranteed.

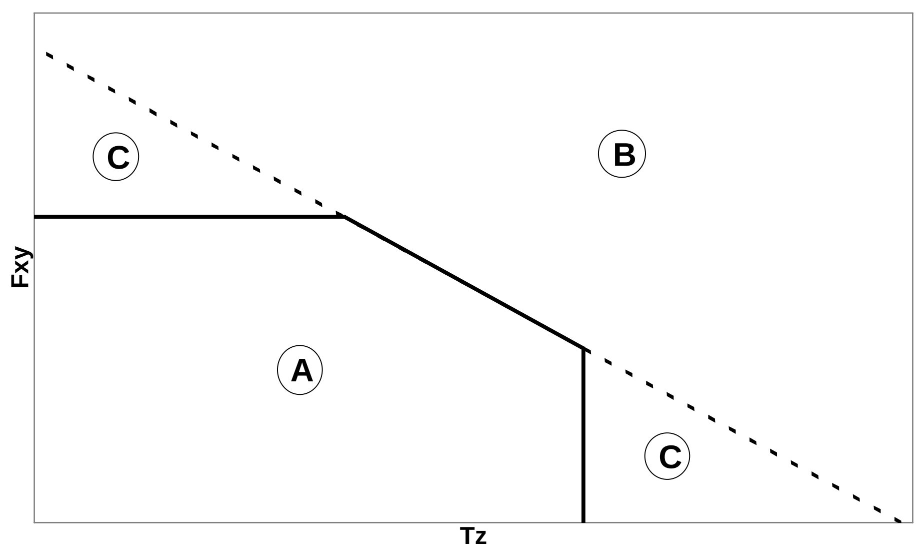


Figure 3.2—Complex loading sample graph

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4. Transducer Specifications

4.1 Nano17

4.1.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-3-1**	**US-6-2**	**US-12-4**	**SI-12-0.12**	**SI-25-0.25**	**SI-50-0.5**
Rated Sensing Ranges						
Fx, Fy	±3 lbf	±6 lbf	±12 lbf	±12 N	±25 N	±50 N
Fz	±4.25 lbf	±8.5 lbf	±17 lbf	±17 N	±35 N	±70 N
Tx, Ty, Tz	±1 lbf-in	±2 lbf-in	±4 lbf-in	±120 Nmm	±250 Nmm	±500 Nmm
Resolution (minimum)*						
Fx, Fy	1/1280 lbf	1/640 lbf	1/320 lbf	1/320 N	1/160 N	1/80 N
Fz	1/1280 lbf	1/640 lbf	1/320 lbf	1/320 N	1/160 N	1/80 N
Tx, Ty	1/8000 lbf-in	1/4000 lbf-in	1/2000 lbf-in	1/64 Nmm	1/32 Nmm	1/16 Nmm
Tz	1/8000 lbf-in	1/4000 lbf-in	1/2000 lbf-in	1/64 Nmm	1/32 Nmm	1/16 Nmm

*DAQ resolutions are typical for a 16-bit data acquisition system

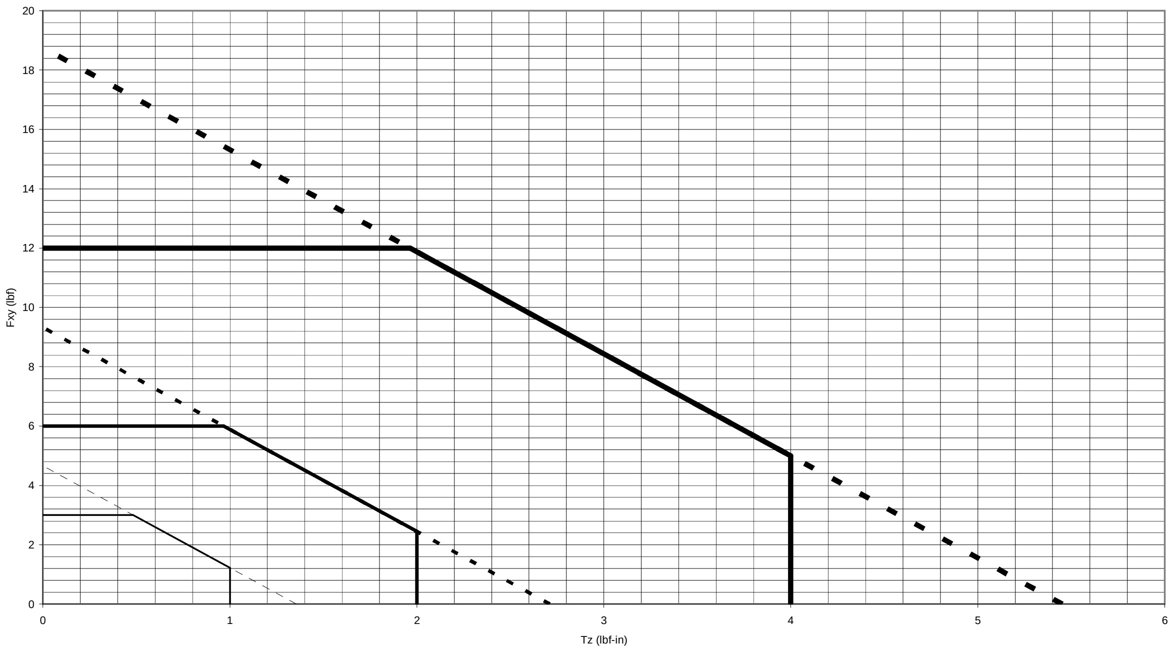
4.1.2 CTL Calibration Specifications

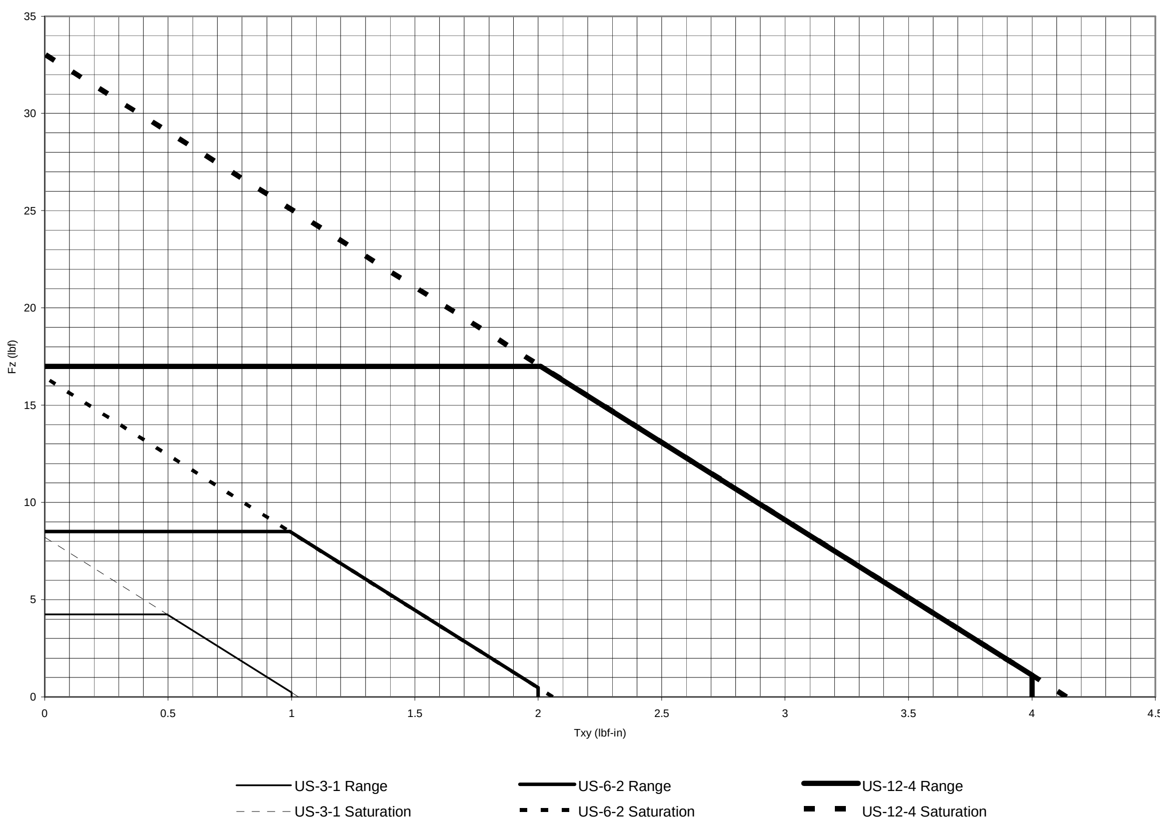
	US (English)			SI (Metric)		
Calibration	**US-3-1**	**US-6-2**	**US-12-4**	**SI-12-0.12**	**SI-25-0.25**	**SI-50-0.5**
Rated Sensing Ranges						
Fx, Fy	±3 lbf	±6 lbf	±12 lbf	±12 N	±25 N	±50 N
Fz	±4.25 lbf	±8.5 lbf	±17 lbf	±17 N	±35 N	±70 N
Tx, Ty, Tz	±1 lbf-in	±2 lbf-in	±4 lbf-in	±120 Nmm	±250 Nmm	±500 Nmm
Resolution (minimum)						
Fx, Fy	1/640 lbf	1/320 lbf	1/160 lbf	1/160 N	1/80 N	1/40 N
Fz	1/640 lbf	1/320 lbf	1/160 lbf	1/160 N	1/80 N	1/40 N
Tx, Ty	1/4000 lbf-in	1/2000 lbf-in	1/1000 lbf-in	1/32 Nmm	1/16 Nmm	1/8 Nmm
Tz	1/4000 lbf-in	1/2000 lbf-in	1/1000 lbf-in	1/32 Nmm	1/16 Nmm	1/8 Nmm
Counts Value						
Fx, Fy, Fz	5120 / lbf	2560 / lbf	1280 / lbf	1280 / N	640 / N	320 / N
Tx, Ty, Tz	32000 / lbf-in	16000 / lbf-in	8000 / lbf-in	256 / Nmm	128 / Nmm	64 / Nmm
Analog Output						
Analog Range						
Fx, Fy	±3 lbf	±6 lbf	±12 lbf	±12 N	±25 N	±50 N
Fz	±4.25 lbf	±8.5 lbf	±17 lbf	±17 N	±35 N	±70 N
Tx, Ty, Tz	±1 lbf-in	±2 lbf-in	±4 lbf-in	±120 Nmm	±250 Nmm	±500 Nmm
±5V Sensitivity						
Fx, Fy	0.6 lbf/V	1.2 lbf/V	2.4 lbf/V	2.4 N/V	5 N/V	10 N/V
Fz	0.85 lbf/V	1.7 lbf/V	3.4 lbf/V	3.4 N/V	7 N/V	14 N/V
Tx, Ty, Tz	0.2 lbf-in/V	0.4 lbf-in/V	0.8 lbf-in/V	24 Nmm/V	50 Nmm/V	100 Nmm/V
±10V Sensitivity						
Fx, Fy	0.3 lbf/V	0.6 lbf/V	1.2 lbf/V	1.2 N/V	2.5 N/V	5 N/V
Fz	0.425 lbf/V	0.85 lbf/V	1.7 lbf/V	1.7 N/V	3.5 N/V	7 N/V
Tx, Ty, Tz	0.1 lbf-in/V	0.2 lbf-in/V	0.4 lbf-in/V	12 Nmm/V	25 Nmm/V	50 Nmm/V
Tool Transform Factor	0.0016 in/unit	0.0016 in/unit	0.0016 in/unit	0.05 mm/unit	0.05 mm/unit	0.05 mm/unit

4.1.3 Nano17 Physical Properties

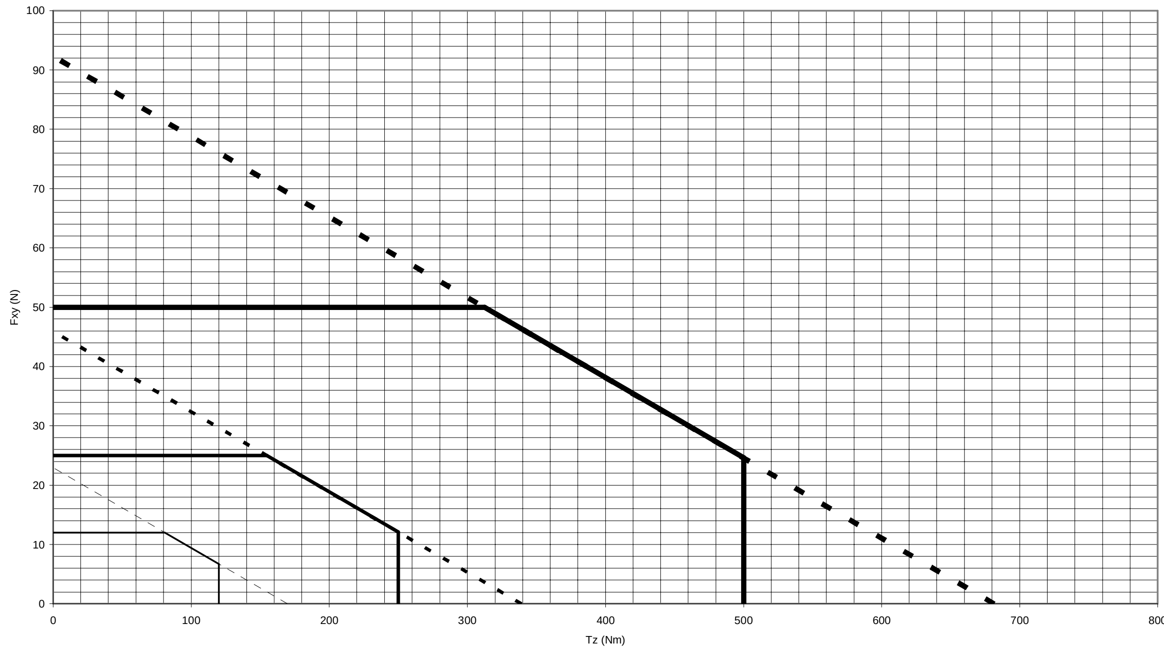
	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	47.E+3 lbf/in	8.2E+6 N/m
Z-axis force (Kz)	65.E+3 lbf/in	11.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	2.1E+3 in-lbf/rad	240.E+0 Nm/rad
Z-axis torque (Ktz)	3.4E+3 in-lbf/rad	380.E+0 Nm/rad
Resonance (Measured)		
Fx, Fy, Tz	7.2 kHz	
Fz, Tx, Ty	7.2 kHz	
Maximum Single-axis Load		
Fx, Fy	±79. lbf	±350. N
Fz	±150. lbf	±690. N
Tx, Ty	±19. lbf-in	±2.2 Nm
Tz	±25. lbf-in	±2.9 Nm
Weight (excluding cable)		
Transducer with standard aluminum plates	0.021 lb	9.4 g
Transducer with stainless steel plates	0.073 lb.	33 g

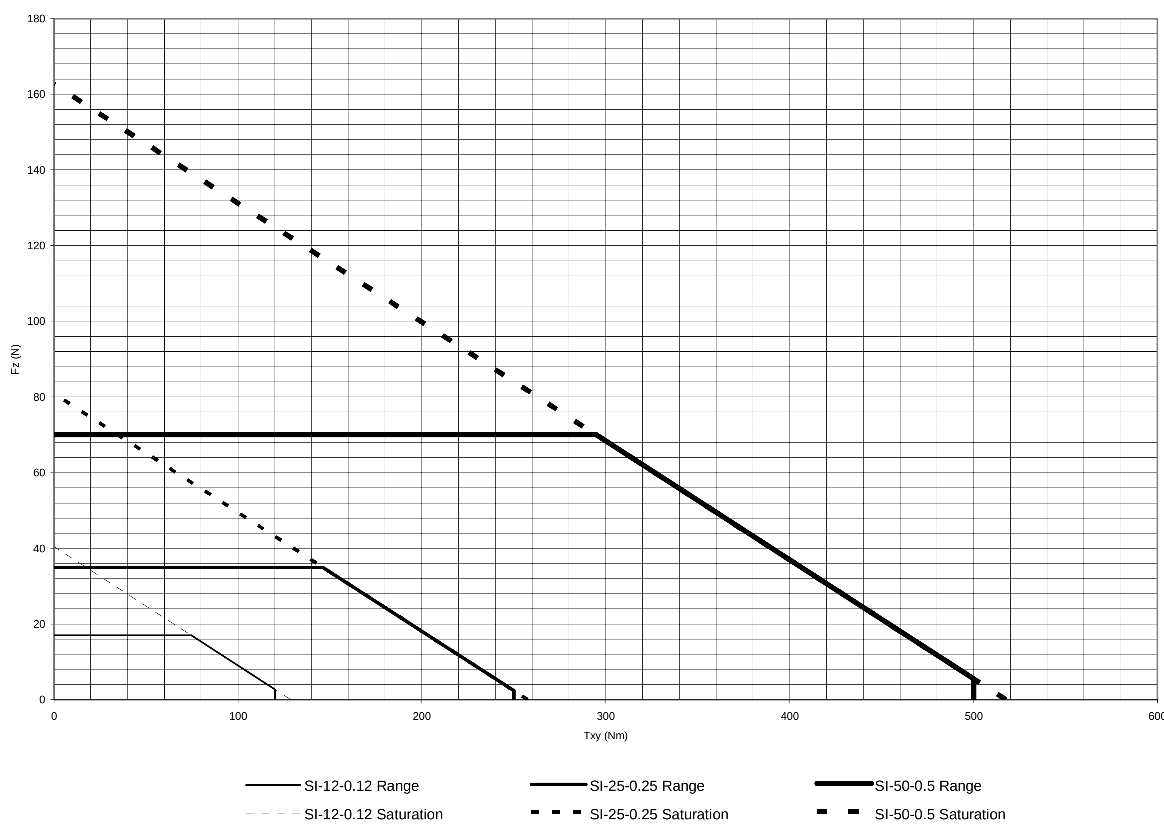
4.1.4 Nano17 (US Calibration Complex Loading)



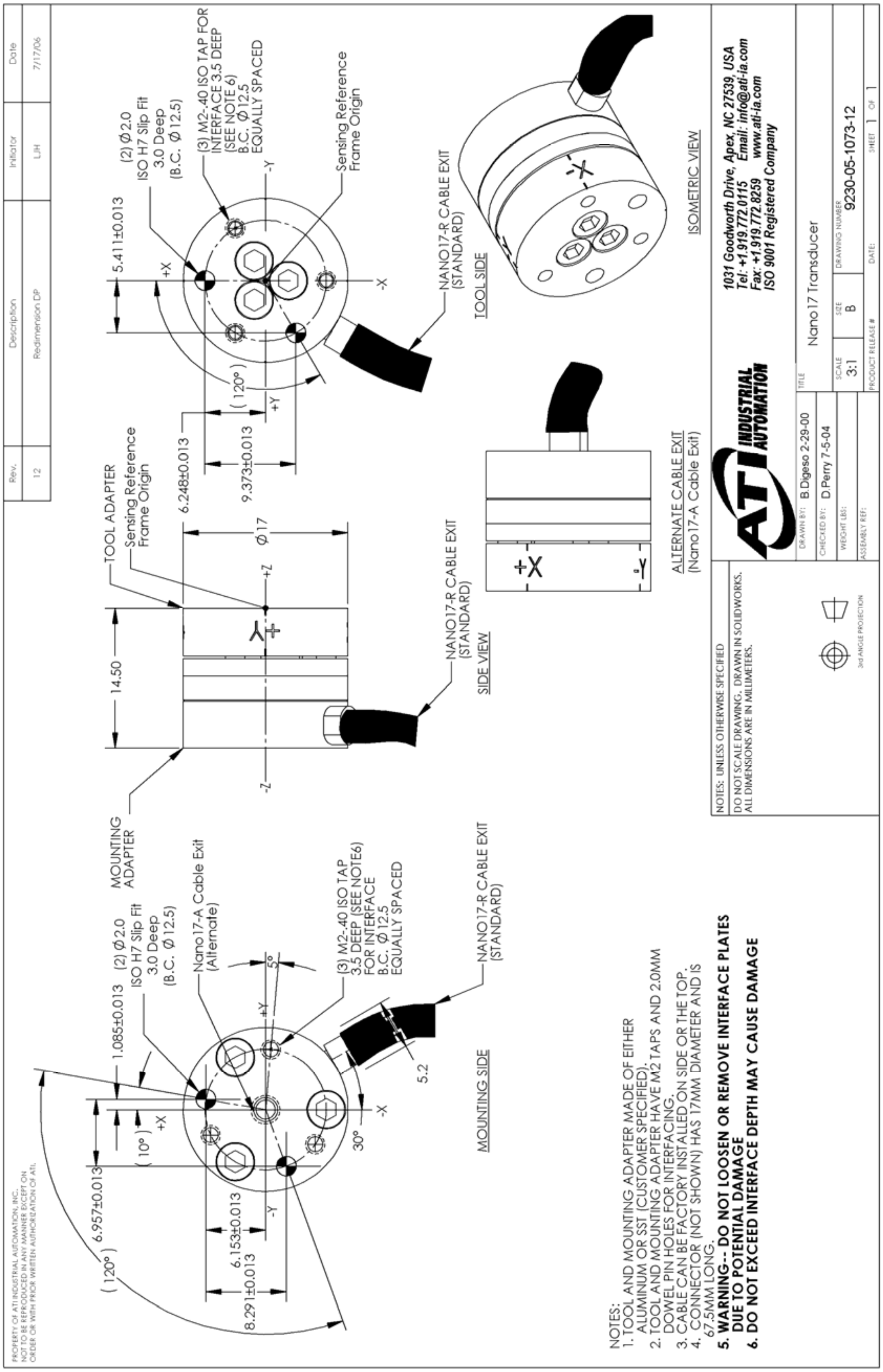


4.1.5 Nano17 (SI Calibration Complex Loading)





4.1.6 Nano17 Transducer



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4.2 Nano25—(Includes IP65 Version)

4.2.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-25-25**	**US-50-50**		**SI-125-3**	**SI-250-6**	
Rated Sensing Ranges						
Fx, Fy	±25 lbf	±50 lbf		±125 N	±250 N	
Fz	±100 lbf	±200 lbf		±500 N	±1000 N	
Tx, Ty, Tz	±25 lbf-in	±50 lbf-in		±3 Nm	±6 Nm	
Resolution (minimum)*						
Fx, Fy	1/224 lbf	1/112 lbf		1/48 N	1/24 N	
Fz	3/224 lbf	3/112 lbf		1/16 N	1/8 N	
Tx, Ty	1/160 lbf-in	1/80 lbf-in		1/1320 Nm	1/660 Nm	
Tz	1/320 lbf-in	1/160 lbf-in		1/2640 Nm	1/1320 Nm	

*DAQ resolutions are typical for a 16-bit data acquisition system

4.2.2 CTL Calibration Specifications

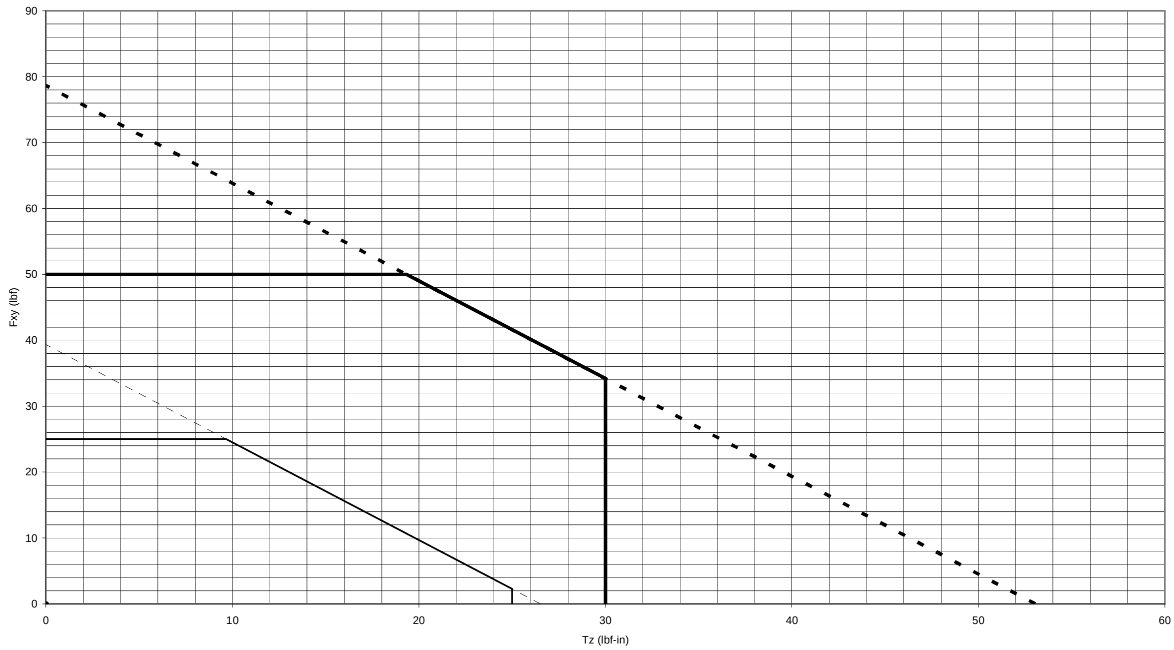
	US (English)			SI (Metric)		
Calibration	**US-25-25**	**US-50-50**		**SI-125-3**	**SI-250-6**	
Rated Sensing Ranges						
Fx, Fy	±25 lbf	±50 lbf		±125 N	±250 N	
Fz	±100 lbf	±200 lbf		±500 N	±1000 N	
Tx, Ty, Tz	±25 lbf-in	±50 lbf-in		±3 Nm	±6 Nm	
Resolution (minimum)						
Fx, Fy	1/112 lbf	1/56 lbf		1/24 N	1/12 N	
Fz	3/112 lbf	3/56 lbf		1/8 N	1/4 N	
Tx, Ty	1/80 lbf-in	1/40 lbf-in		1/660 Nm	1/330 Nm	
Tz	1/160 lbf-in	1/80 lbf-in		1/1320 Nm	1/660 Nm	
Counts Value						
Fx, Fy, Fz	896 / lbf	448 / lbf		192 / N	96 / N	
Tx, Ty, Tz	1280 / lbf-in	640 / lbf-in		10560 / Nm	5280 / Nm	
Analog Output						
Analog Range						
Fx, Fy	±25 lbf	±50 lbf		±125 N	±250 N	
Fz	±100 lbf	±200 lbf		±500 N	±1000 N	
Tx, Ty, Tz	±25 lbf-in	±50 lbf-in		±3 Nm	±6 Nm	
±5V Sensitivity						
Fx, Fy	5 lbf/V	10 lbf/V		25 N/V	50 N/V	
Fz	20 lbf/V	40 lbf/V		100 N/V	200 N/V	
Tx, Ty, Tz	5 lbf-in/V	10 lbf-in/V		0.6 Nm/V	1.2 Nm/V	
±10V Sensitivity						
Fx, Fy	2.5 lbf/V	5 lbf/V		12.5 N/V	25 N/V	
Fz	10 lbf/V	20 lbf/V		50 N/V	100 N/V	
Tx, Ty, Tz	2.5 lbf-in/V	5 lbf-in/V		0.3 Nm/V	0.6 Nm/V	
Tool Transform Factor	0.007 in/unit	0.007 in/unit		0.18182 mm/unit	0.18182 mm/unit	

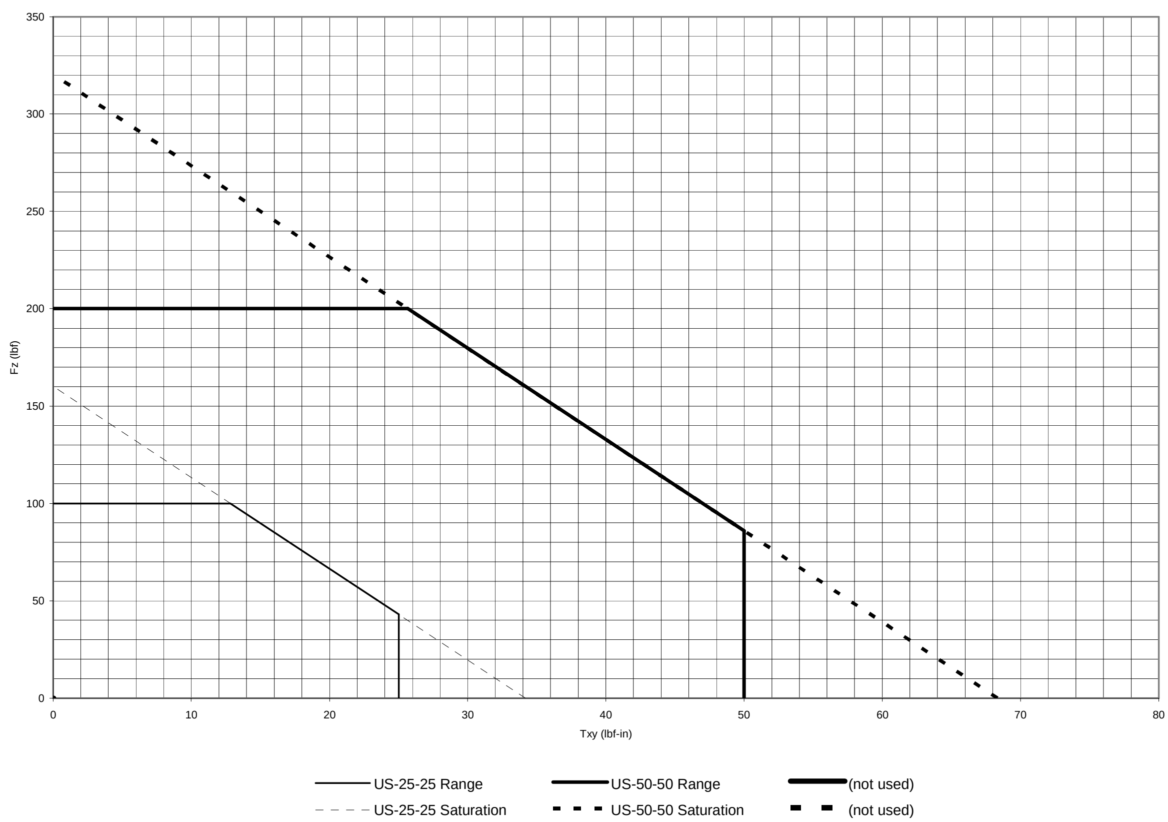
Note: Applying moments beyond ±30 in-lb (±3.4Nm) in Tz can cause hysteresis and permanent zero-point change in the Nano25 (applies to all versions of the Nano25).

4.2.3 Nano25 Physical Properties (Includes IP65 Version)

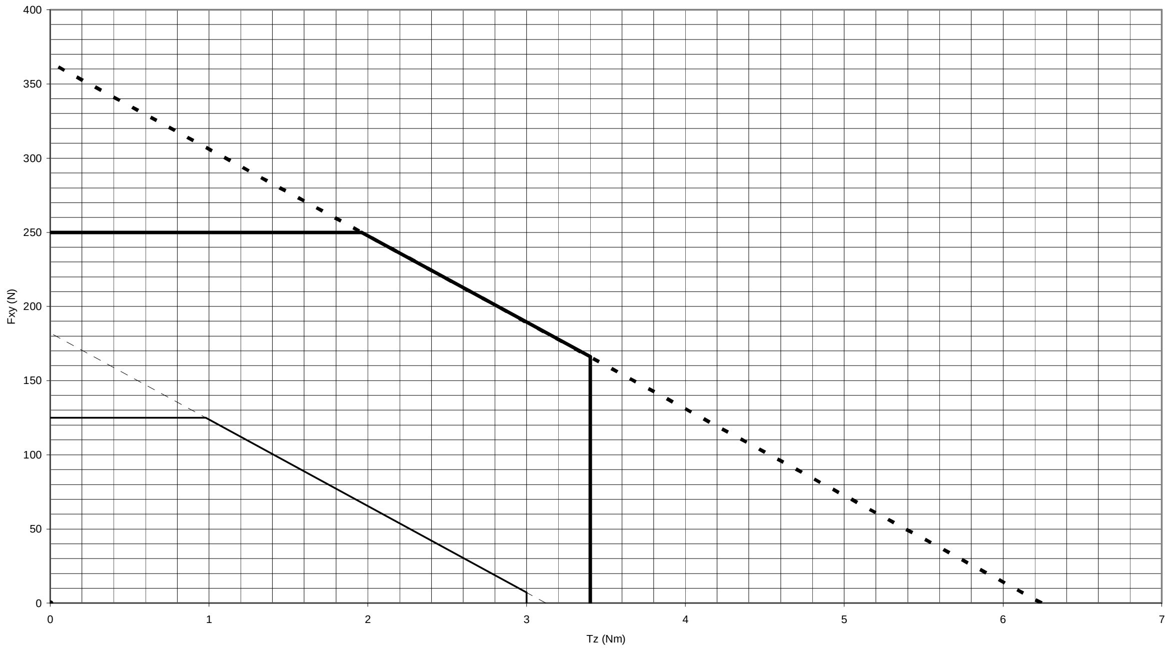
	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	300.E+3 lbf/in	53.E+6 N/m
Z-axis force (Kz)	630.E+3 lbf/in	110.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	57.E+3 in-lbf/rad	6.5E+3 Nm/rad
Z-axis torque (Ktz)	81.E+3 in-lbf/rad	9.2E+3 Nm/rad
Resonance (Measured, non-IP Version)		
Fx, Fy, Tz	3.8 kHz	
Fz, Tx, Ty	3.6 kHz	
Resonance (Measured, IP65 Version)		
Fx, Fy, Tz	3.4 kHz	
Fz, Tx, Ty	3.5 kHz	
Maximum Single-axis Load		
Fx, Fy	±520. lbf	±2,300. N
Fz	±1,600. lbf	±7,300. N
Tx, Ty	±370. lbf-in	±42. Nm
Tz	±550. lbf-in	±62. Nm
Weight (excluding cable)		
Transducer with stainless steel plates	0.14 lb	65 g
IP65	0.30 lb	136 g

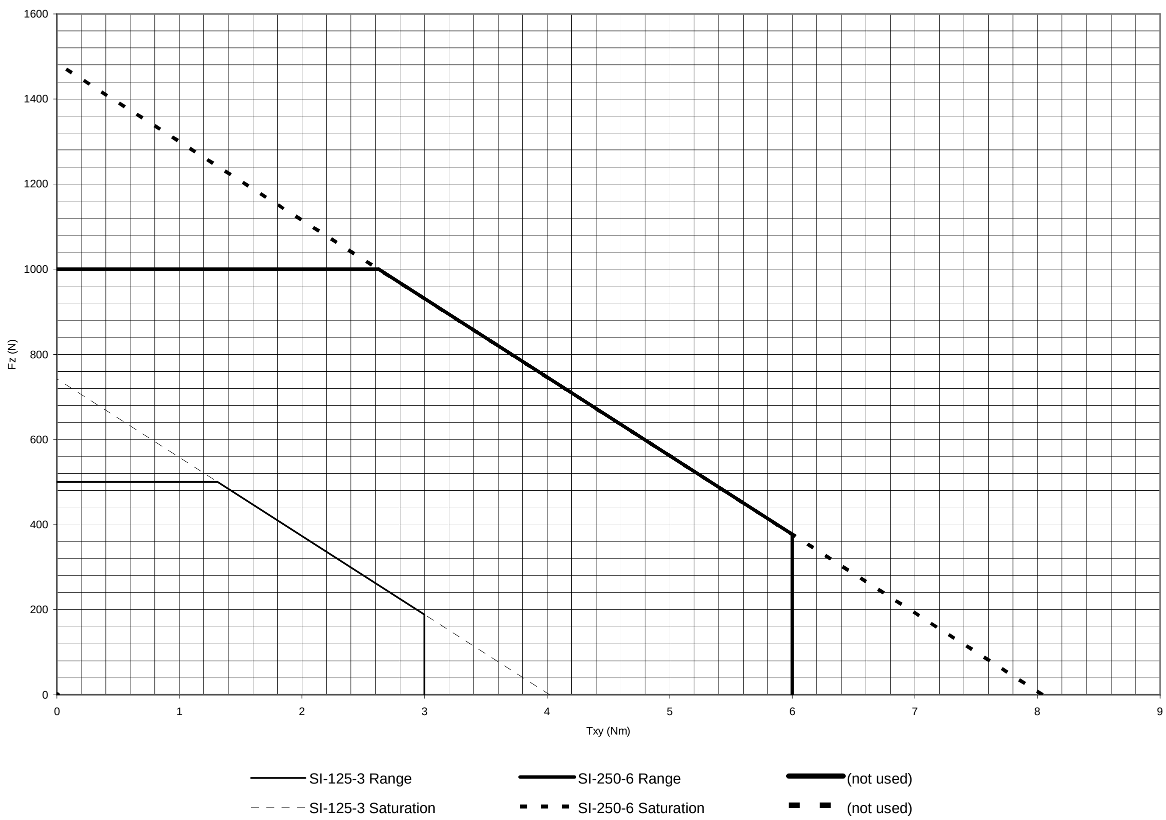
4.2.4 Nano25 (US Calibration Complex Loading) (Includes IP65 Version)



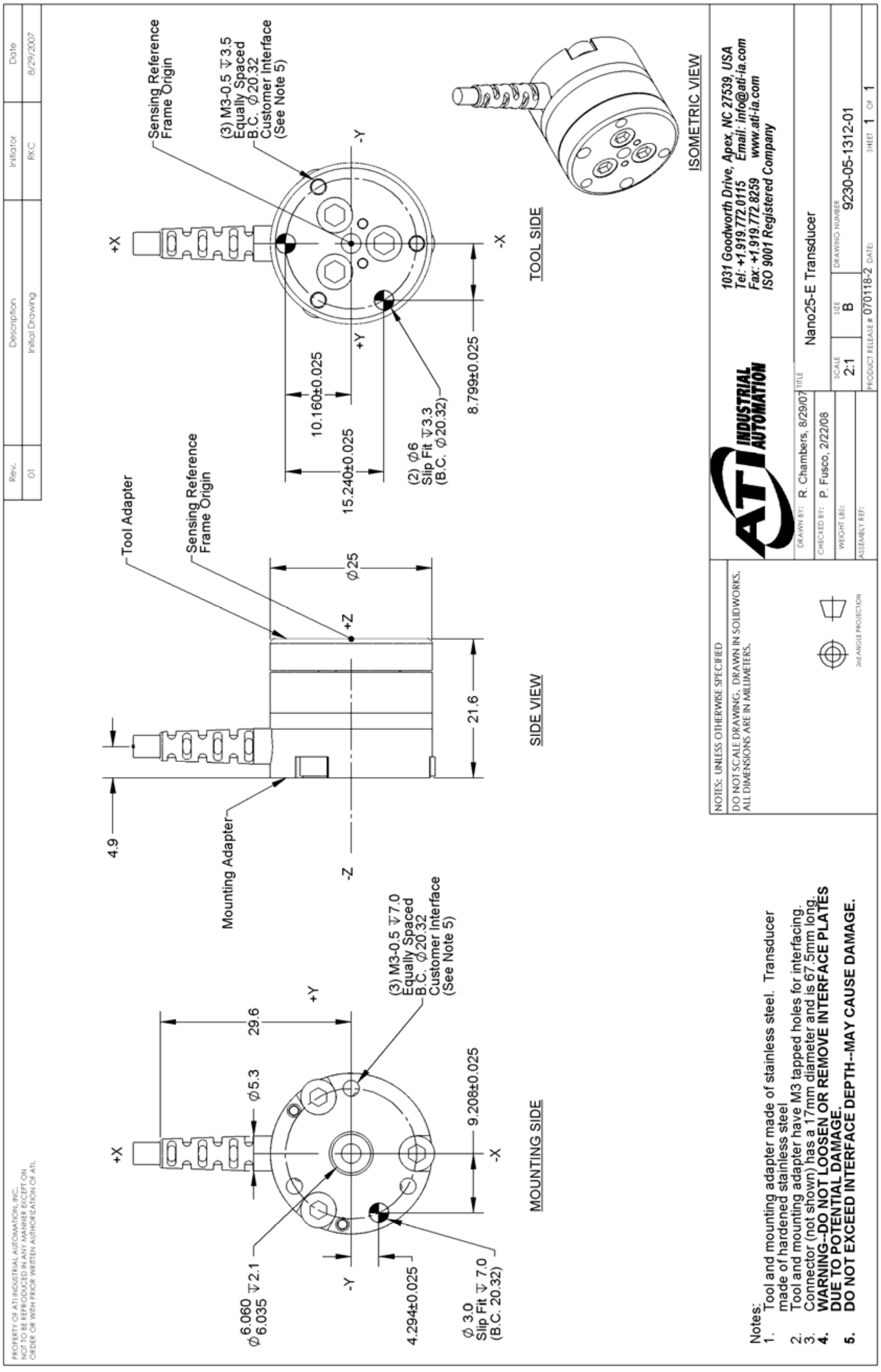


4.2.5 Nano25 (SI Calibration Complex Loading) (Includes IP65 Version)

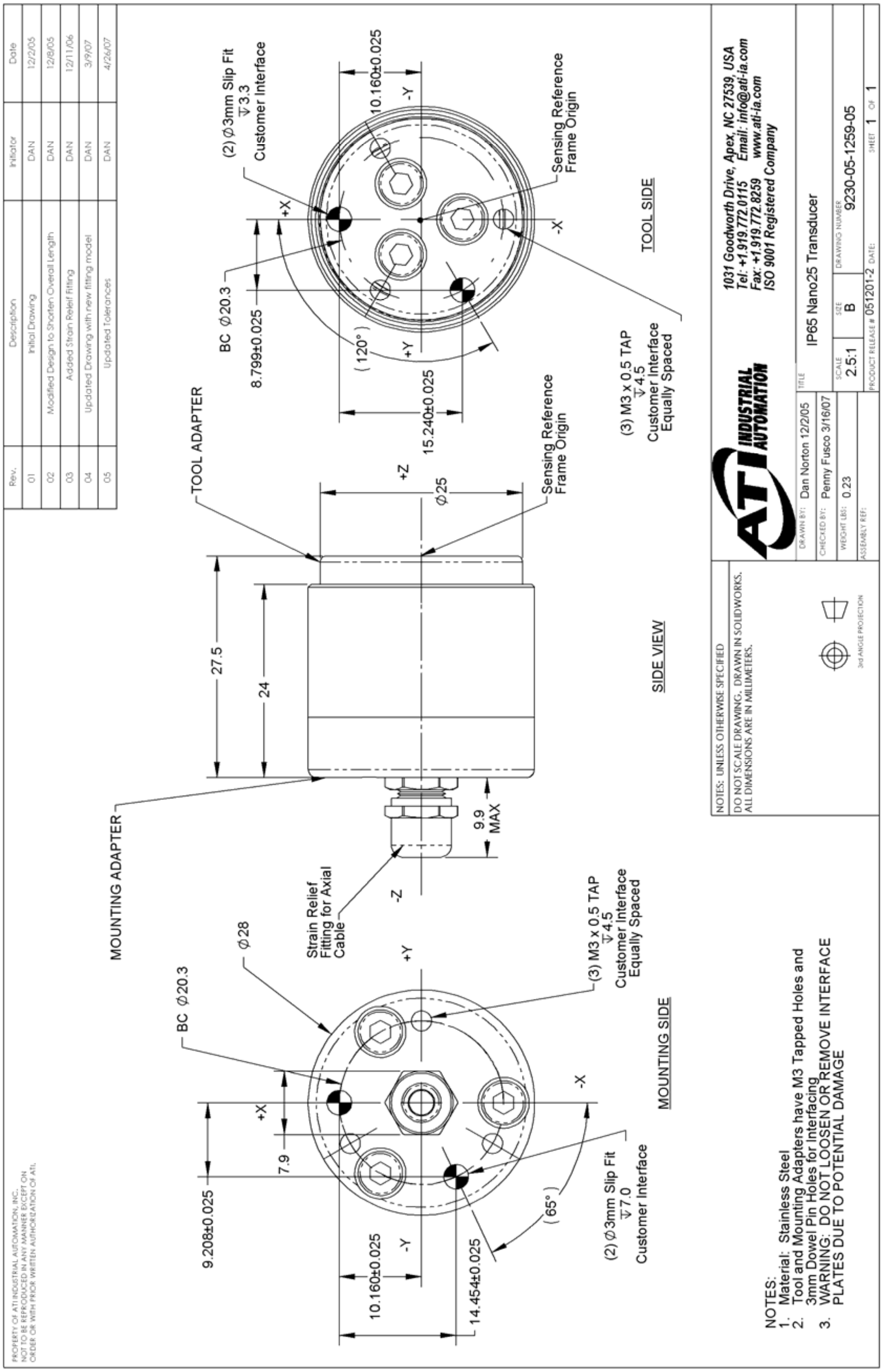




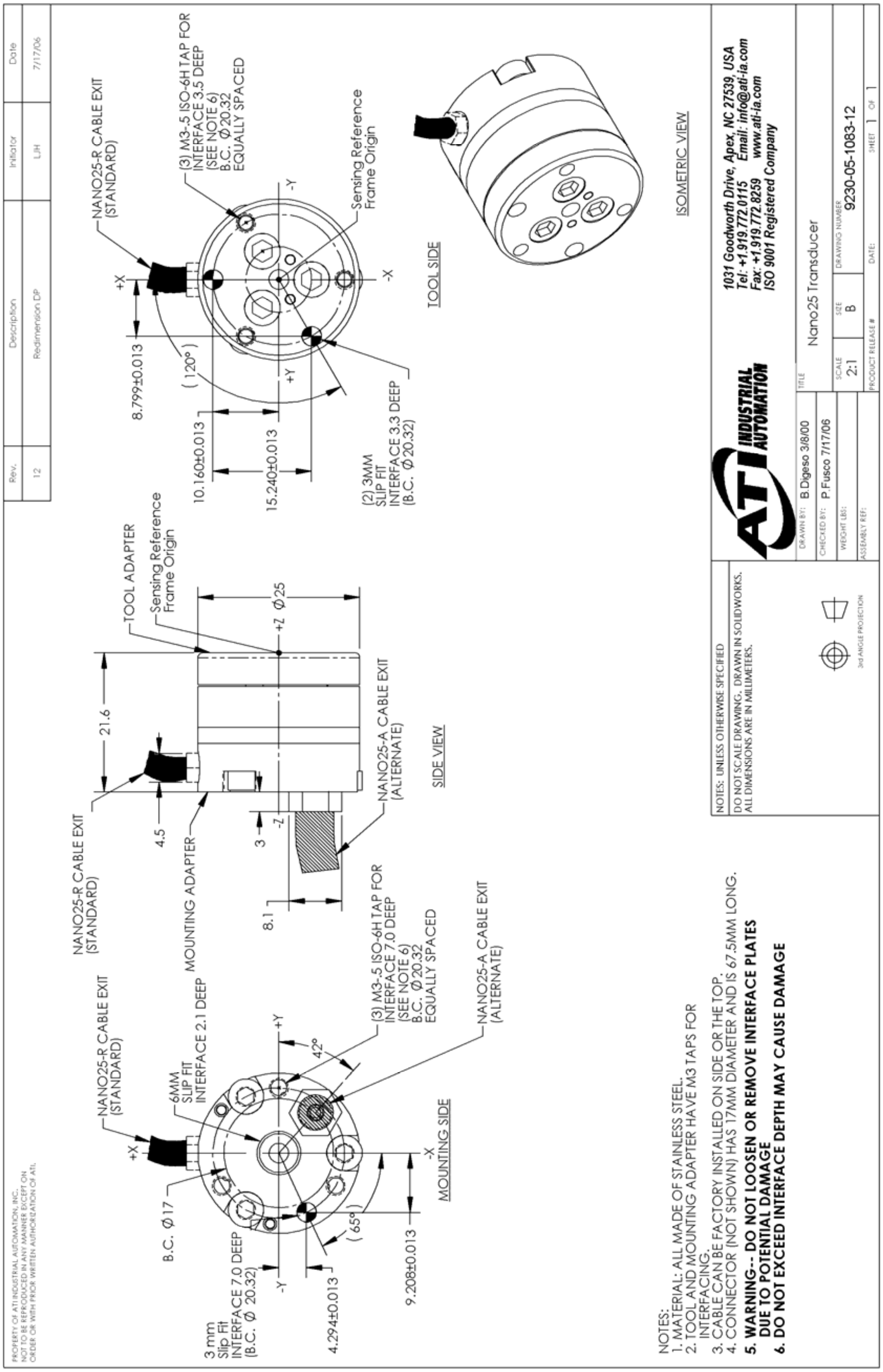
4.2.6 Nano25-E Transducer



4.2.7 Nano25 IP65 Transducer



4.2.8 Legacy Nano25 Transducer



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4.3 Nano43

4.3.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			**SI (Metric)**		
Calibration	**US-4-2**	**US-8-4**		**SI-18-0.25**	**SI-36-0.5**	
Rated Sensing Ranges						
Fx, Fy	±4 lbf	±8 lbf		±18 N	±36 N	
Fz	±4 lbf	±8 lbf		±18 N	±36 N	
Tx, Ty, Tz	±2 lbf-in	±4 lbf-in		±250 Nmm	±500 Nmm	
Resolution (minimum)*						
Fx, Fy	1/1160 lbf	1/580 lbf		1/256 N	1/128 N	
Fz	1/1160 lbf	1/580 lbf		1/256 N	1/128 N	
Tx, Ty	1/2320 lbf-in	1/1160 lbf-in		1/20 Nmm	1/10 Nmm	
Tz	1/2320 lbf-in	1/1160 lbf-in		1/20 Nmm	1/10 Nmm	

*DAQ resolutions are typical for a 16-bit data acquisition system

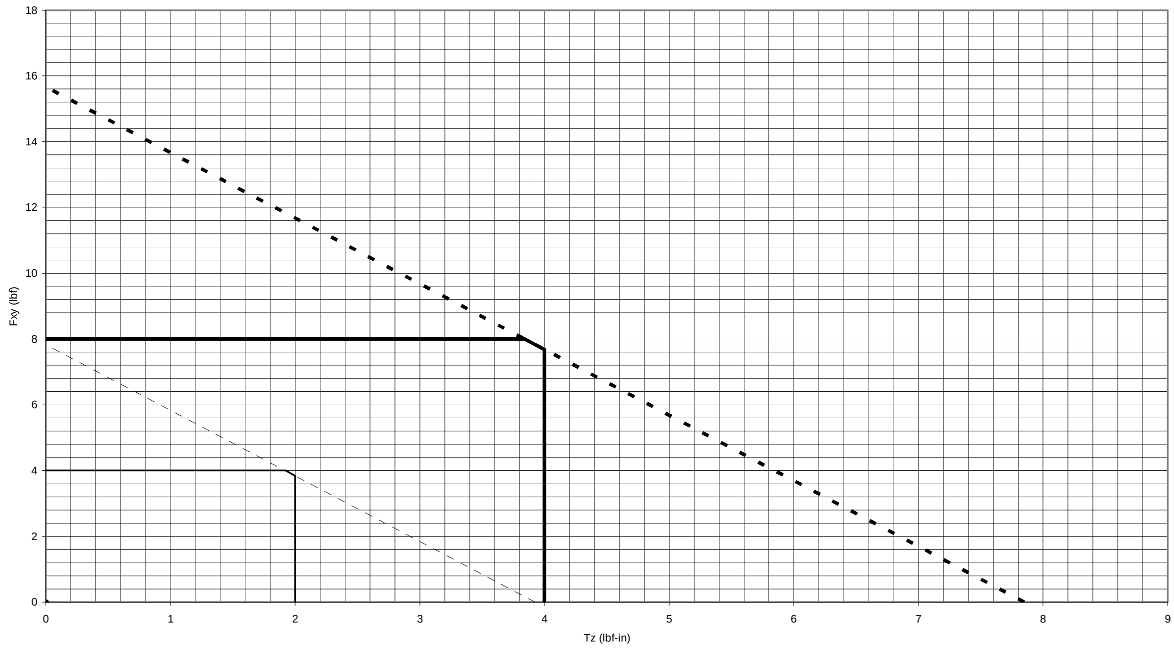
4.3.2 CTL Calibration Specifications

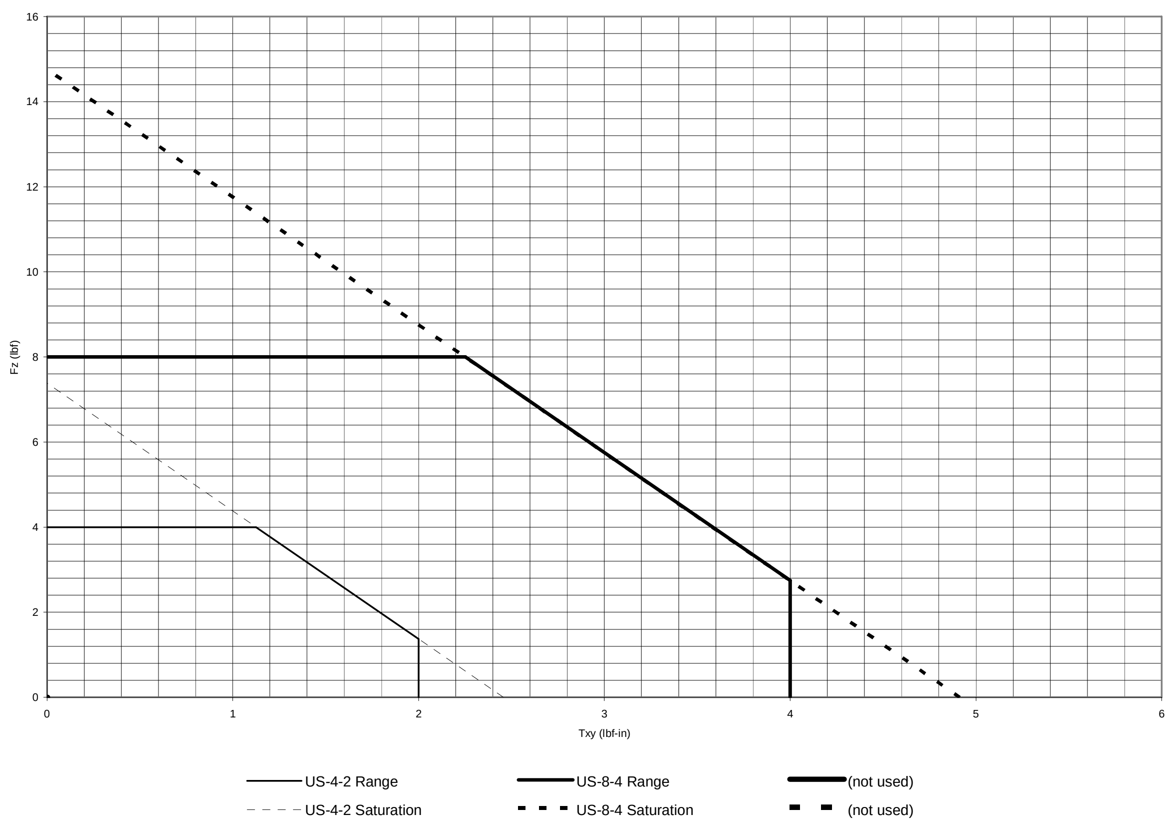
	US (English)			**SI (Metric)**		
Calibration	**US-4-2**	**US-8-4**		**SI-18-0.25**	**SI-36-0.5**	
Rated Sensing Ranges						
Fx, Fy	±4 lbf	±8 lbf		±18 N	±36 N	
Fz	±4 lbf	±8 lbf		±18 N	±36 N	
Tx, Ty, Tz	±2 lbf-in	±4 lbf-in		±250 Nmm	±500 Nmm	
Resolution (minimum)						
Fx, Fy	1/580 lbf	1/290 lbf		1/128 N	1/64 N	
Fz	1/580 lbf	1/290 lbf		1/128 N	1/64 N	
Tx, Ty	1/1160 lbf-in	1/580 lbf-in		1/10 Nmm	1/5 Nmm	
Tz	1/1160 lbf-in	1/580 lbf-in		1/10 Nmm	1/5 Nmm	
Counts Value						
Fx, Fy, Fz	4640 / lbf	2320 / lbf		1024 / N	512 / N	
Tx, Ty, Tz	9280 / lbf-in	4640 / lbf-in		80 / Nmm	40 / Nmm	
Analog Output						
Analog Range						
Fx, Fy	±4 lbf	±8 lbf		±18 N	±36 N	
Fz	±4 lbf	±8 lbf		±18 N	±36 N	
Tx, Ty, Tz	±2 lbf-in	±4 lbf-in		±250 Nmm	±500 Nmm	
±5V Sensitivity						
Fx, Fy	0.8 lbf/V	1.6 lbf/V		3.6 N/V	7.2 N/V	
Fz	0.8 lbf/V	1.6 lbf/V		3.6 N/V	7.2 N/V	
Tx, Ty, Tz	0.4 lbf-in/V	0.8 lbf-in/V		50 Nmm/V	100 Nmm/V	
±10V Sensitivity						
Fx, Fy	0.4 lbf/V	0.8 lbf/V		1.8 N/V	3.6 N/V	
Fz	0.4 lbf/V	0.8 lbf/V		1.8 N/V	3.6 N/V	
Tx, Ty, Tz	0.2 lbf-in/V	0.4 lbf-in/V		25 Nmm/V	50 Nmm/V	
Tool Transform Factor	0.005 in/unit	0.005 in/unit		0.128 mm/unit	0.128 mm/unit	

4.3.3 Nano43 Physical Properties

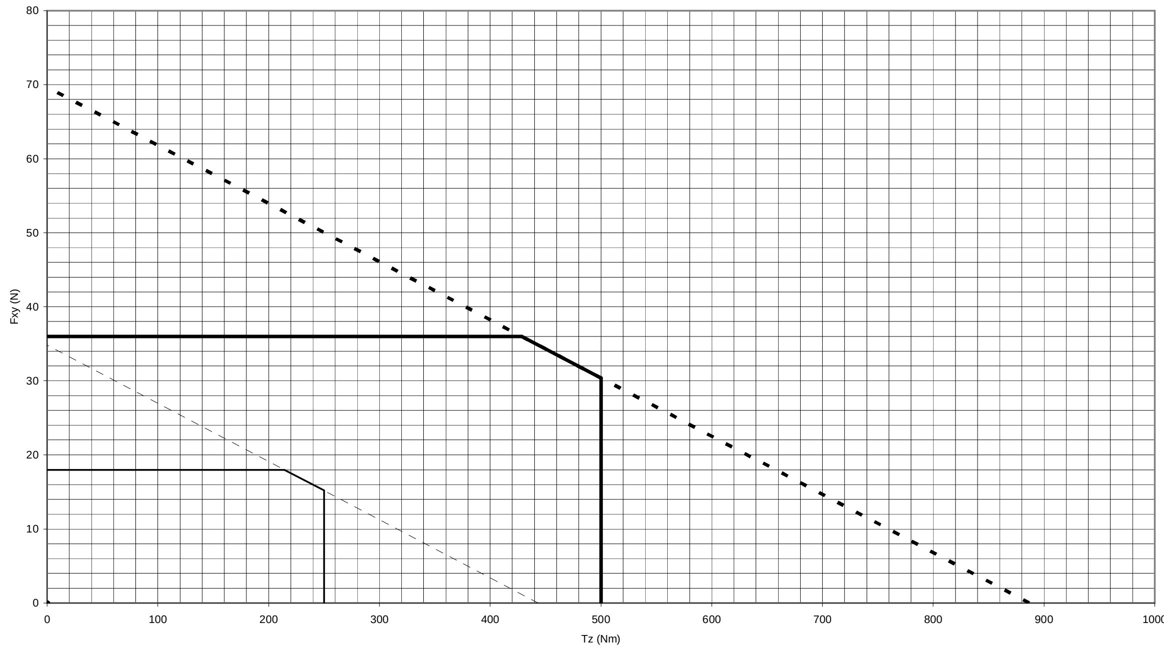
	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	29.E+3 lbf/in	5.2E+6 N/m
Z-axis force (Kz)	29.E+3 lbf/in	5.2E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	6.8E+3 in-lbf/rad	770.E+0 Nm/rad
Z-axis torque (Ktz)	10.E+3 in-lbf/rad	1.1E+3 Nm/rad
Maximum Single-axis Load		
Fx, Fy	±67. lbf	±300. N
Fz	±88. lbf	±390. N
Tx, Ty	±29. lbf-in	±3.3 Nm
Tz	±47. lbf-in	±5.3 Nm
Weight (excluding cable)		
Transducer with standard aluminum plates	0.085 lb	38 g
Transducer with stainless steel plates	0.18 lb	82 g

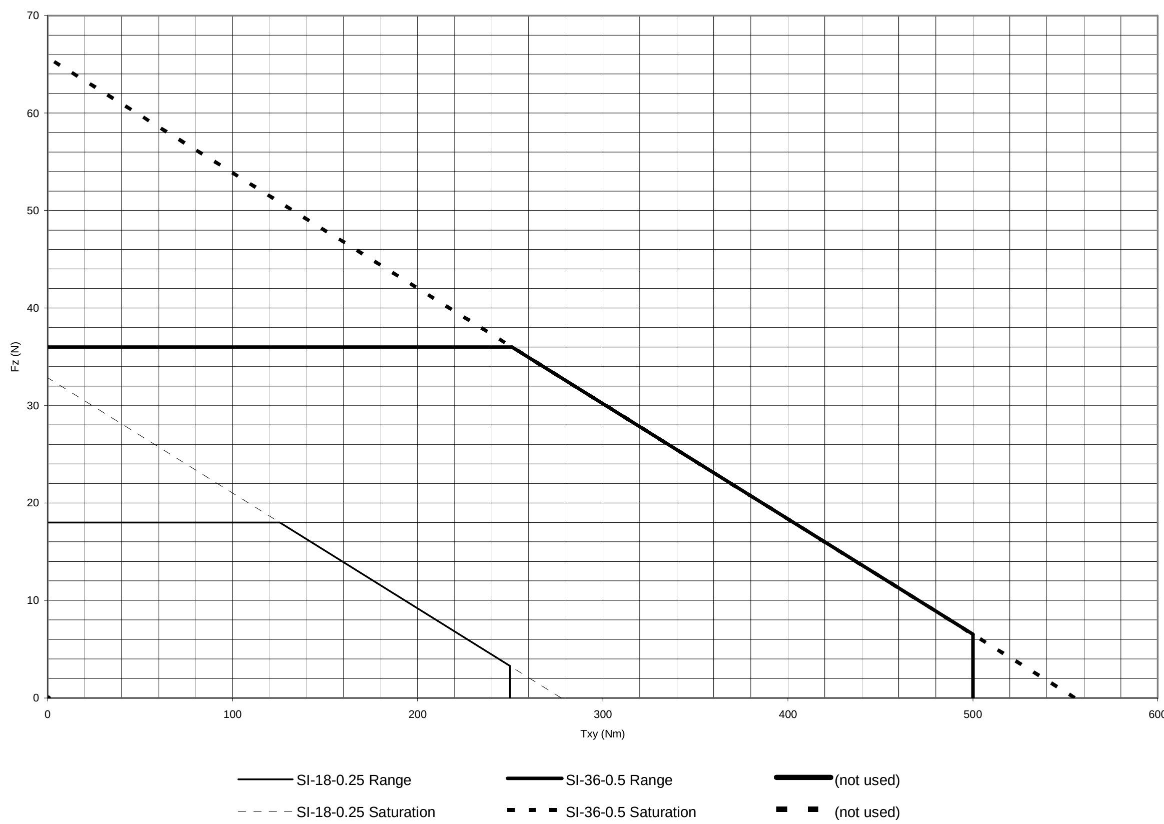
4.3.4 Nano43 (US Calibration Complex Loading)



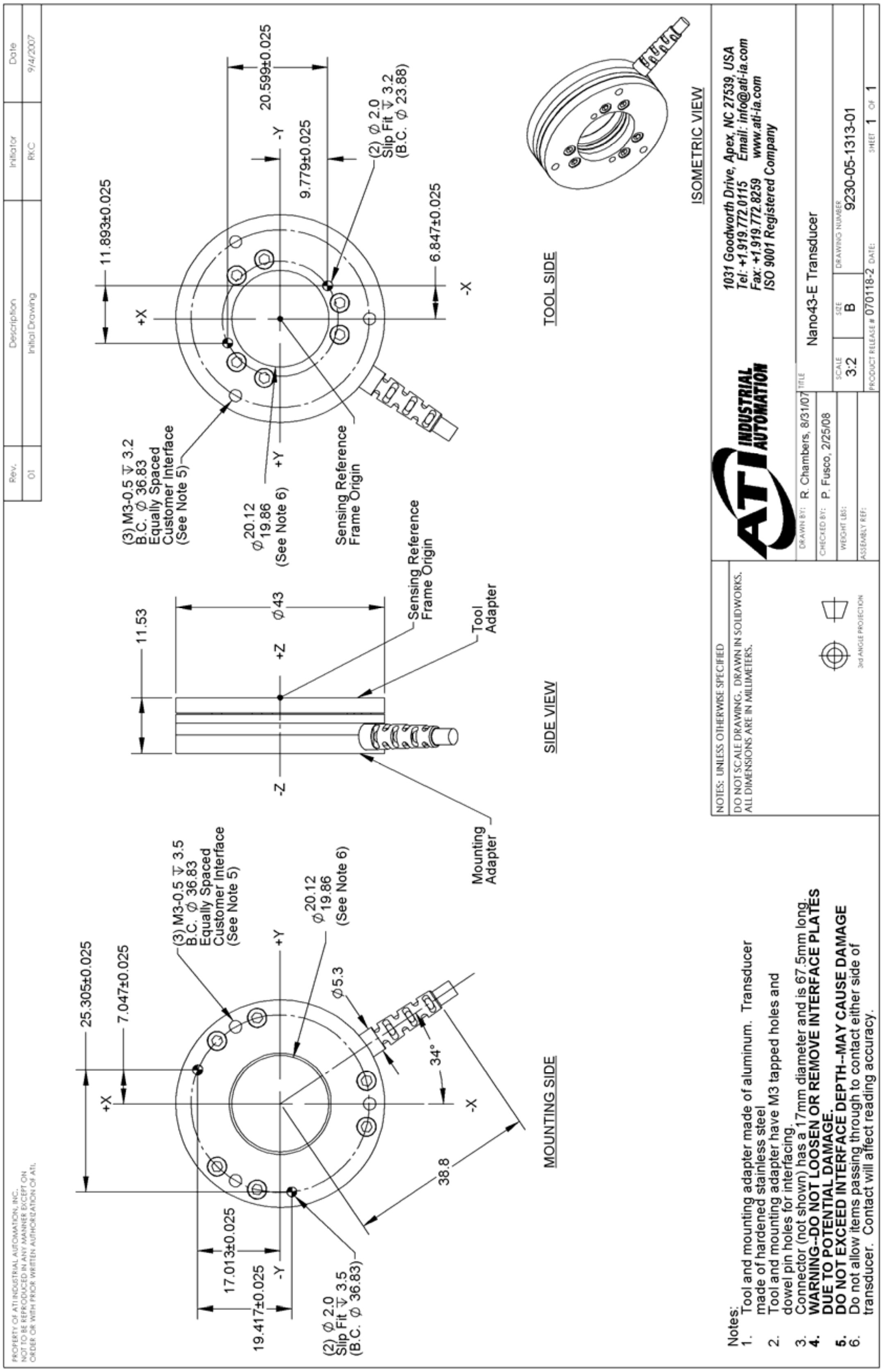


4.3.5 Nano43 (SI Calibration Complex Loading)

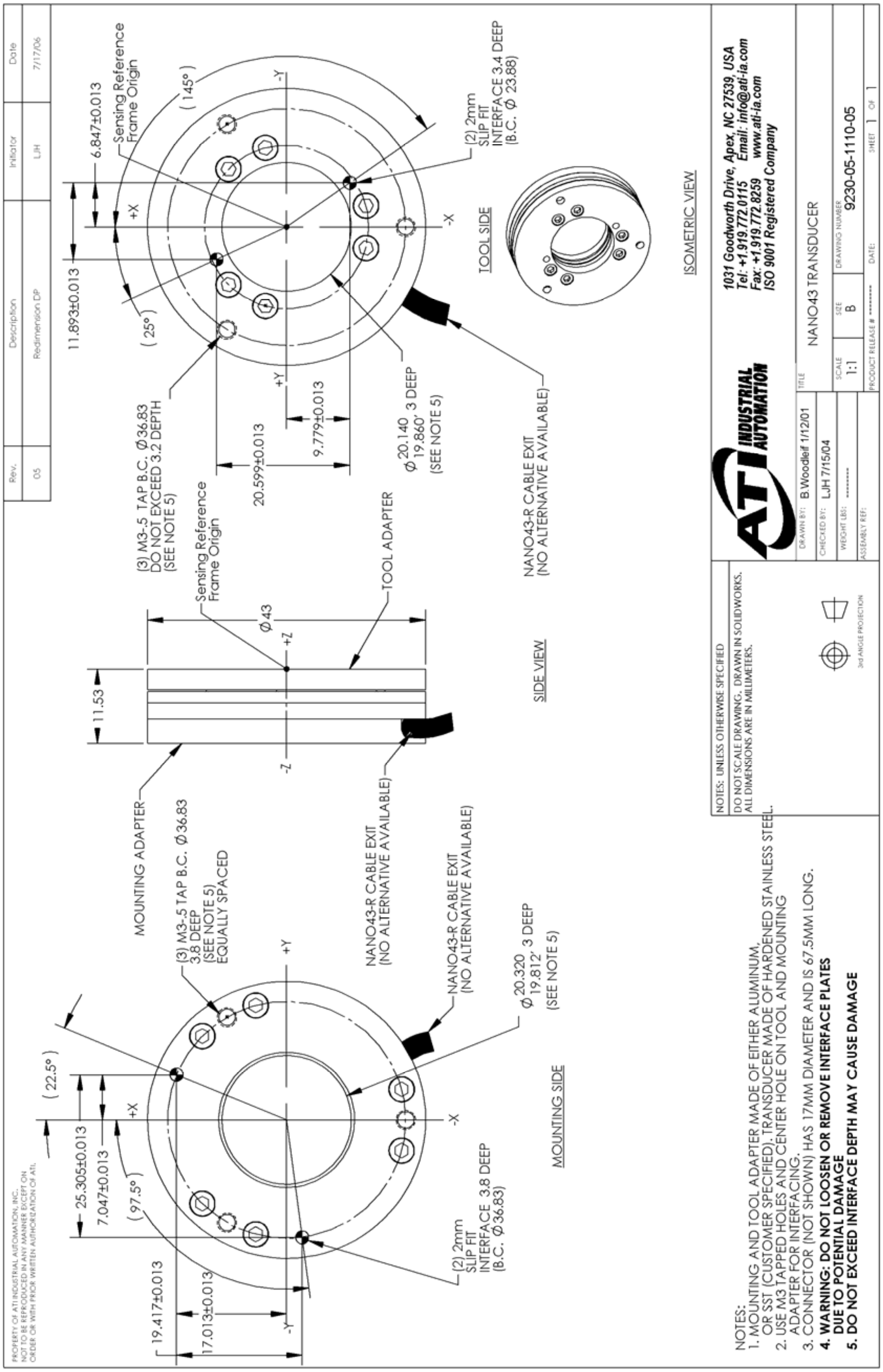




4.3.6 Nano43-E Transducer



4.3.7 Legacy Nano43 Transducer



4.4 Mini40

4.4.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-5-10**	**US-10-20**	**US-20-40**	**SI-20-1**	**SI-40-2**	**SI-80-4**
Rated Sensing Ranges						
Fx, Fy	±5 lbf	±10 lbf	±20 lbf	±20 N	±40 N	±80 N
Fz	±15 lbf	±30 lbf	±60 lbf	±60 N	±120 N	±240 N
Tx, Ty, Tz	±10 lbf-in	±20 lbf-in	±40 lbf-in	±1 Nm	±2 Nm	±4 Nm
Resolution (minimum)*						
Fx, Fy	1/800 lbf	1/400 lbf	1/200 lbf	1/200 N	1/100 N	1/50 N
Fz	1/400 lbf	1/200 lbf	1/100 lbf	1/100 N	1/50 N	1/25 N
Tx, Ty	1/800 lbf-in	1/400 lbf-in	1/200 lbf-in	1/8000 Nm	1/4000 Nm	1/2000 Nm
Tz	1/800 lbf-in	1/400 lbf-in	1/200 lbf-in	1/8000 Nm	1/4000 Nm	1/2000 Nm

*DAQ resolutions are typical for a 16-bit data acquisition system

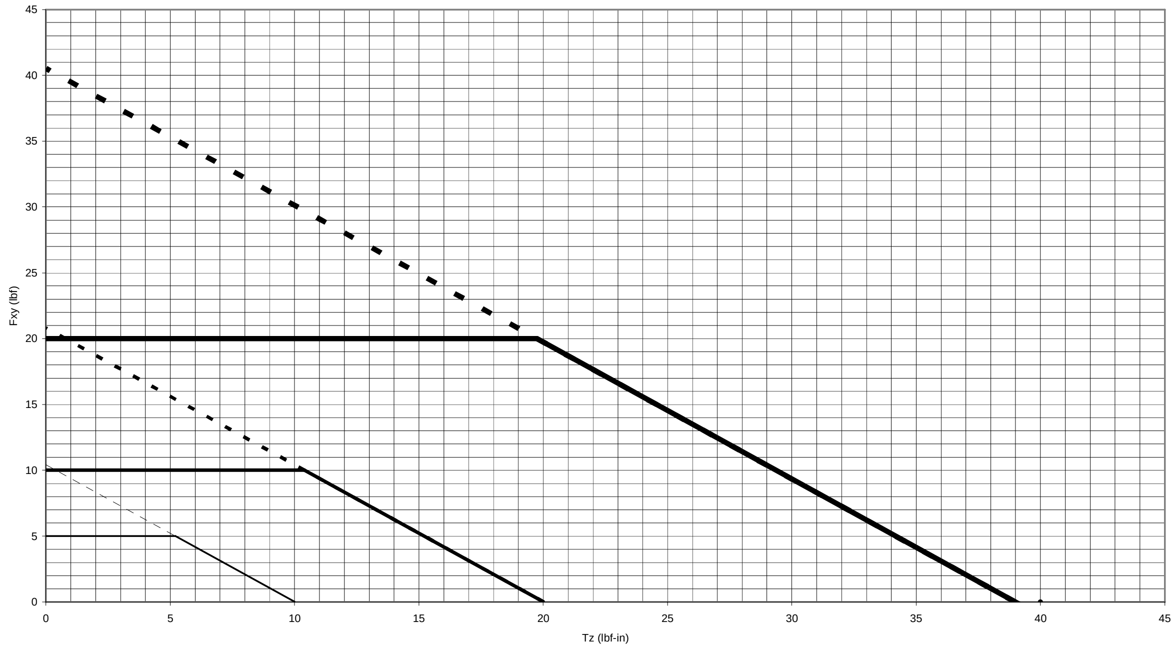
4.4.2 CTL Calibration Specifications

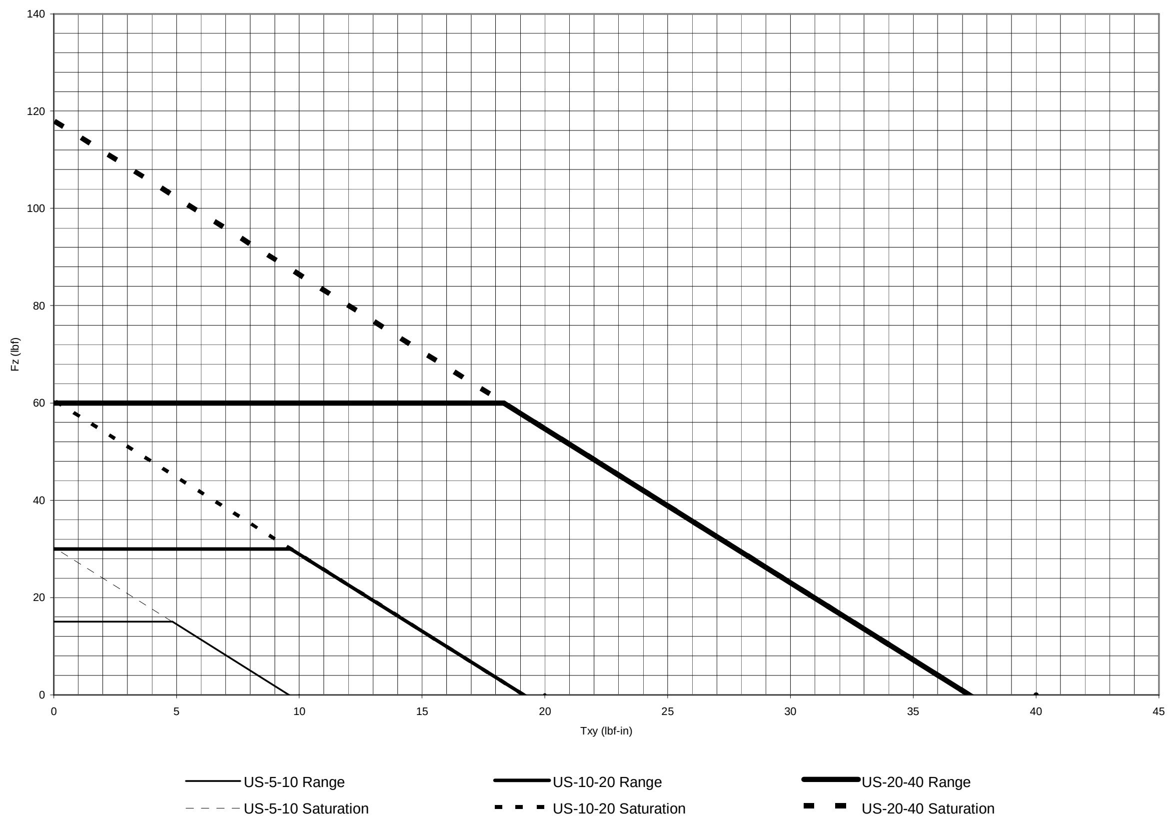
	US (English)			SI (Metric)		
Calibration	**US-5-10**	**US-10-20**	**US-20-40**	**SI-20-1**	**SI-40-2**	**SI-80-4**
Rated Sensing Ranges						
Fx, Fy	±5 lbf	±10 lbf	±20 lbf	±20 N	±40 N	±80 N
Fz	±15 lbf	±30 lbf	±60 lbf	±60 N	±120 N	±240 N
Tx, Ty, Tz	±10 lbf-in	±20 lbf-in	±40 lbf-in	±1 Nm	±2 Nm	±4 Nm
Resolution (minimum)						
Fx, Fy	1/400 lbf	1/200 lbf	1/100 lbf	1/100 N	1/50 N	1/25 N
Fz	1/200 lbf	1/100 lbf	1/50 lbf	1/50 N	1/25 N	2/25 N
Tx, Ty	1/400 lbf-in	1/200 lbf-in	1/100 lbf-in	1/4000 Nm	1/2000 Nm	1/1000 Nm
Tz	1/400 lbf-in	1/200 lbf-in	1/100 lbf-in	1/4000 Nm	1/2000 Nm	1/1000 Nm
Counts Value						
Fx, Fy, Fz	3200 / lbf	1600 / lbf	800 / lbf	800 / N	400 / N	200 / N
Tx, Ty, Tz	3200 / lbf-in	1600 / lbf-in	800 / lbf-in	32000 / Nm	16000 / Nm	8000 / Nm
Analog Output						
Analog Range						
Fx, Fy	±5 lbf	±10 lbf	±20 lbf	±20 N	±40 N	±80 N
Fz	±15 lbf	±30 lbf	±60 lbf	±60 N	±120 N	±240 N
Tx, Ty, Tz	±10 lbf-in	±20 lbf-in	±40 lbf-in	±1 Nm	±2 Nm	±4 Nm
±5V Sensitivity						
Fx, Fy	1 lbf/V	2 lbf/V	4 lbf/V	4 N/V	8 N/V	16 N/V
Fz	3 lbf/V	6 lbf/V	12 lbf/V	12 N/V	24 N/V	48 N/V
Tx, Ty, Tz	2 lbf-in/V	4 lbf-in/V	8 lbf-in/V	0.2 Nm/V	0.4 Nm/V	0.8 Nm/V
±10V Sensitivity						
Fx, Fy	0.5 lbf/V	1 lbf/V	2 lbf/V	2 N/V	4 N/V	8 N/V
Fz	1.5 lbf/V	3 lbf/V	6 lbf/V	6 N/V	12 N/V	24 N/V
Tx, Ty, Tz	1 lbf-in/V	2 lbf-in/V	4 lbf-in/V	0.1 Nm/V	0.2 Nm/V	0.4 Nm/V
Tool Transform Factor	0.01 in/unit	0.01 in/unit	0.01 in/unit	0.25 mm/unit	0.25 mm/unit	0.25 mm/unit

4.4.3 Mini40 Physical Properties

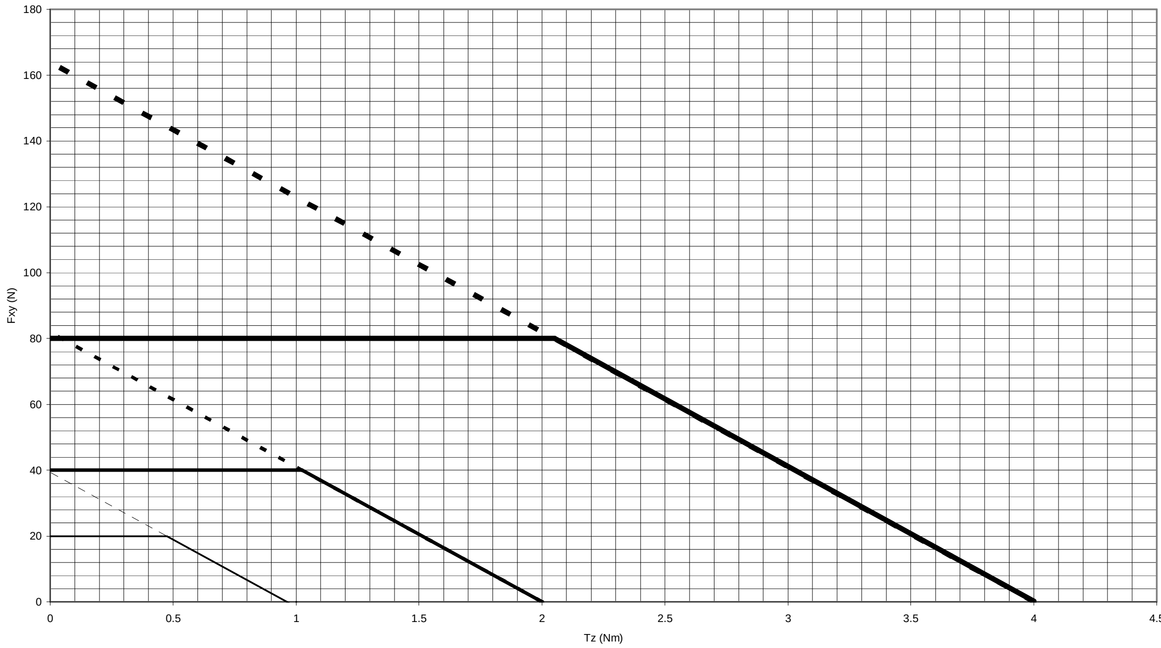
	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	61.E+3 lbf/in	11.E+6 N/m
Z-axis force (Kz)	120.E+3 lbf/in	20.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	25.E+3 in-lbf/rad	2.8E+3 Nm/rad
Z-axis torque (Ktz)	36.E+3 in-lbf/rad	4.E+3 Nm/rad
Resonance (Measured)		
Fx, Fy, Tz	4.9 kHz	
Fz, Tx, Ty	3.2 kHz	
Maximum Single-axis Load		
Fx, Fy	±180. lbf	±810. N
Fz	±530. lbf	±2,300. N
Tx, Ty	±160. lbf-in	±18. Nm
Tz	±170. lbf-in	±19. Nm
Weight (excluding cable)		
Transducer with standard aluminum plates	0.11 lb	50 g
Transducer with stainless steel plates	0.20 lb	91 g

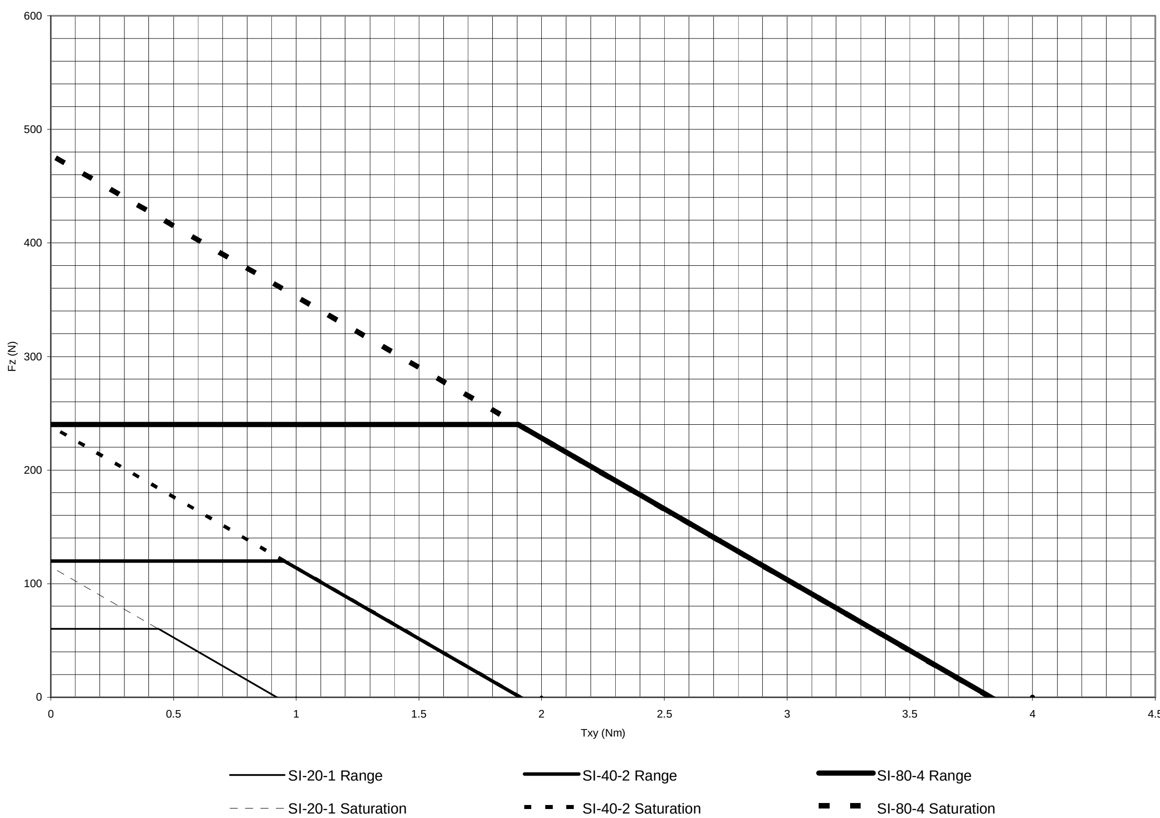
4.4.4 Mini40 (US Calibration Complex Loading)



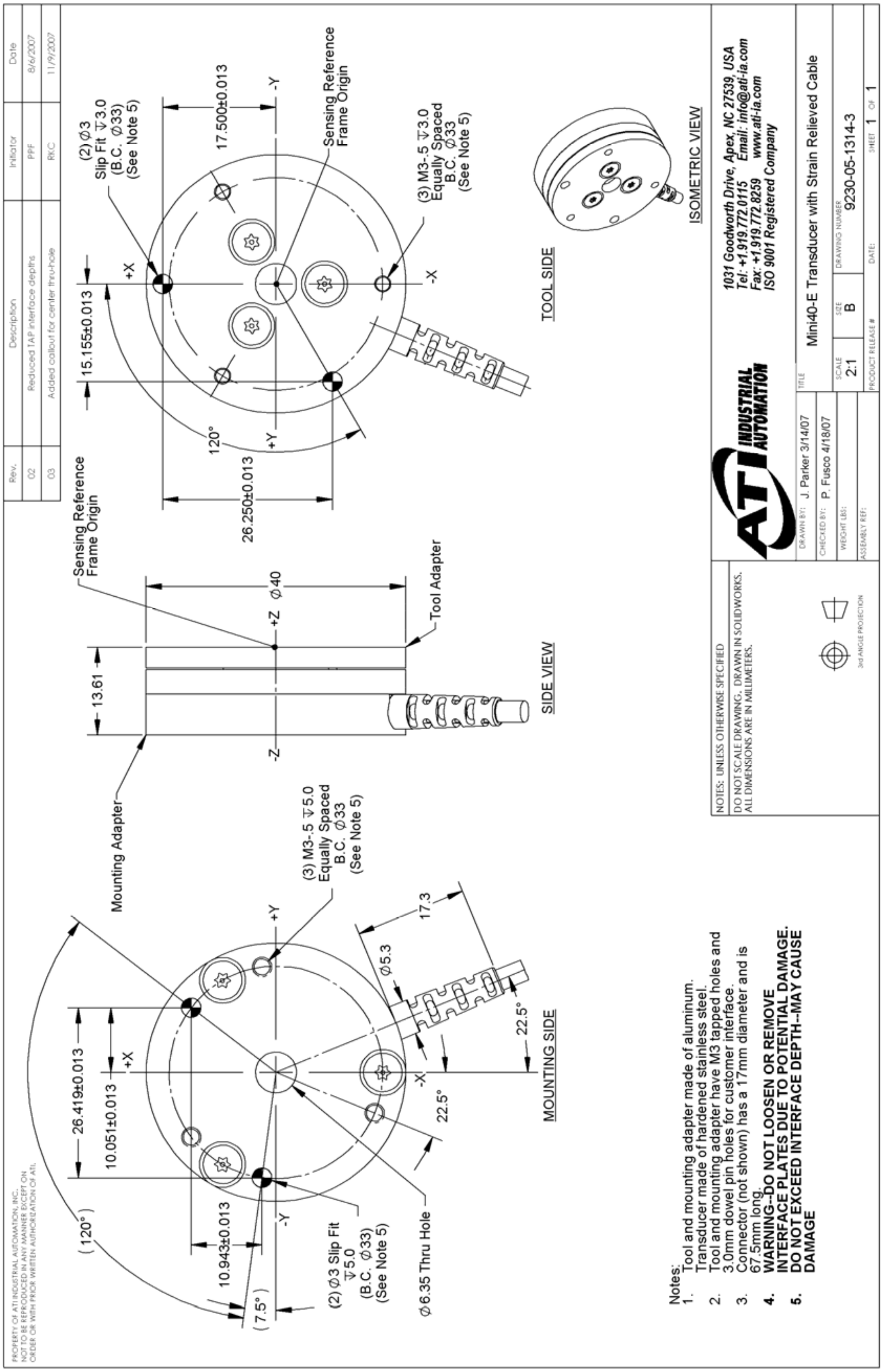


4.4.5 Mini40 (SI Calibration Complex Loading)

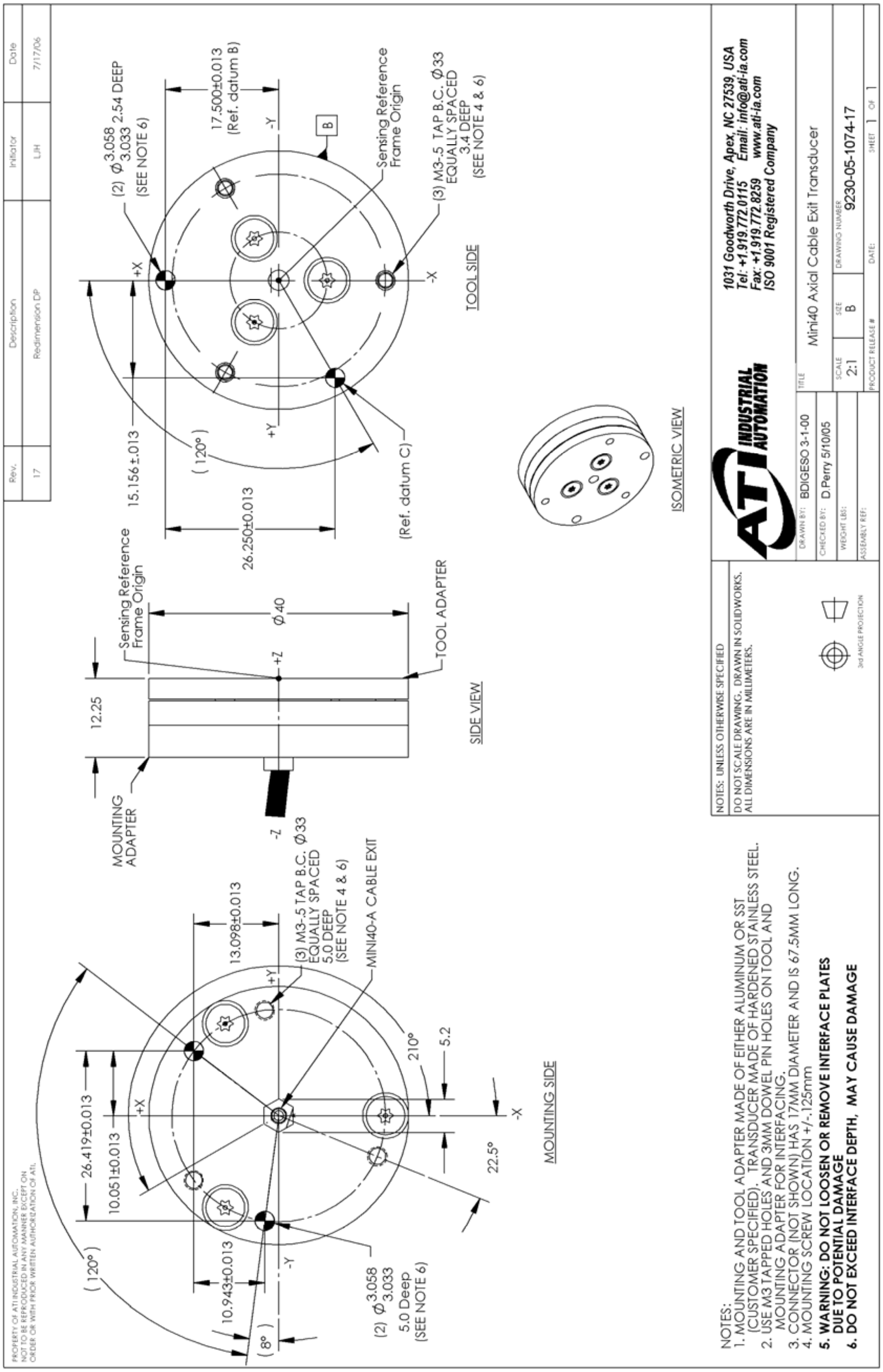




4.4.6 Mini40-E Transducer



4.4.7 Legacy Mini40 Transducer



4.5 Mini45

4.5.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-30-40**	**US-60-80**	**US-120-160**	**SI-145-5**	**SI-290-10**	**SI-580-20**
Rated Sensing Ranges						
Fx, Fy	±30 lbf	±60 lbf	±120 lbf	±145 N	±290 N	±580 N
Fz	±60 lbf	±120 lbf	±240 lbf	±290 N	±580 N	±1160 N
Tx, Ty, Tz	±40 lbf-in	±80 lbf-in	±160 lbf-in	±5 Nm	±10 Nm	±20 Nm
Resolution (minimum)*						
Fx, Fy	1/80 lbf	1/40 lbf	1/20 lbf	1/16 N	1/8 N	1/4 N
Fz	1/80 lbf	1/40 lbf	1/20 lbf	1/16 N	1/8 N	1/4 N
Tx, Ty	1/88 lbf-in	1/44 lbf-in	1/44 lbf-in	1/752 Nm	1/376 Nm	1/188 Nm
Tz	1/176 lbf-in	1/88 lbf-in	1/44 lbf-in	1/1504 Nm	1/752 Nm	1/376 Nm

*DAQ resolutions are typical for a 16-bit data acquisition system

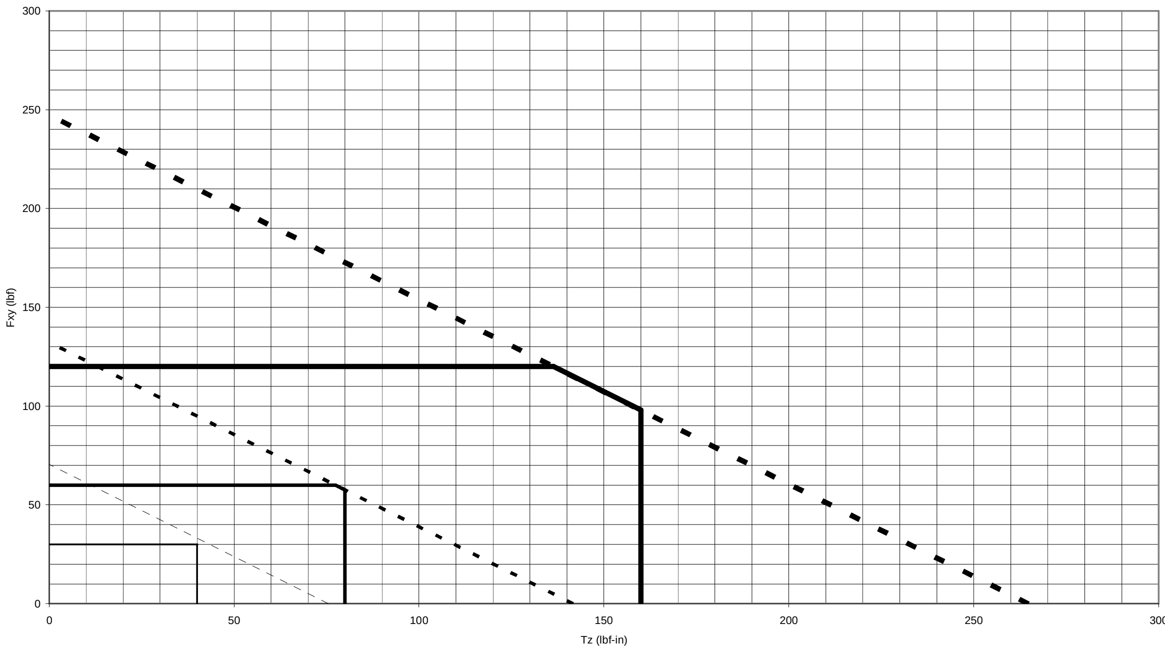
4.5.2 CTL Calibration Specifications

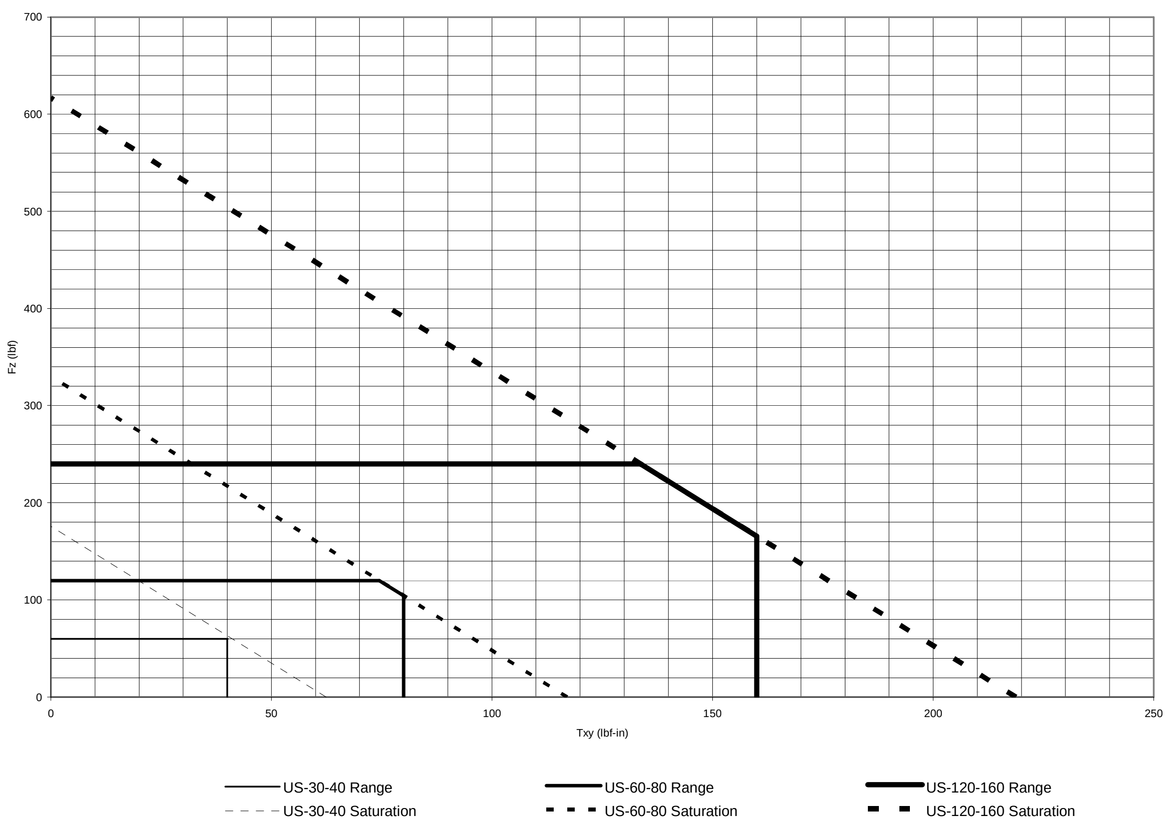
	US (English)			SI (Metric)		
Calibration	**US-30-40**	**US-60-80**	**US-120-160**	**SI-145-5**	**SI-290-10**	**SI-580-20**
Rated Sensing Ranges						
Fx, Fy	±30 lbf	±60 lbf	±120 lbf	±145 N	±290 N	±580 N
Fz	±60 lbf	±120 lbf	±240 lbf	±290 N	±580 N	±1160 N
Tx, Ty, Tz	±40 lbf-in	±80 lbf-in	±160 lbf-in	±5 Nm	±10 Nm	±20 Nm
Resolution (minimum)						
Fx, Fy	1/40 lbf	1/20 lbf	1/10 lbf	1/8 N	1/4 N	1/2 N
Fz	1/40 lbf	1/20 lbf	1/10 lbf	1/8 N	1/4 N	1/2 N
Tx, Ty	1/44 lbf-in	1/22 lbf-in	1/22 lbf-in	1/376 Nm	1/188 Nm	1/94 Nm
Tz	1/88 lbf-in	1/44 lbf-in	1/22 lbf-in	1/752 Nm	1/376 Nm	1/188 Nm
Counts Value						
Fx, Fy, Fz	640 / lbf	320 / lbf	160 / lbf	128 / N	64 / N	32 / N
Tx, Ty, Tz	704 / lbf-in	352 / lbf-in	176 / lbf-in	6016 / Nm	3008 / Nm	1504 / Nm
Analog Output						
Analog Range						
Fx, Fy	±30 lbf	±60 lbf	±120 lbf	±145 N	±290 N	±580 N
Fz	±60 lbf	±120 lbf	±240 lbf	±290 N	±580 N	±1160 N
Tx, Ty, Tz	±40 lbf-in	±80 lbf-in	±160 lbf-in	±5 Nm	±10 Nm	±20 Nm
±5V Sensitivity						
Fx, Fy	6 lbf/V	12 lbf/V	24 lbf/V	29 N/V	58 N/V	116 N/V
Fz	12 lbf/V	24 lbf/V	48 lbf/V	58 N/V	116 N/V	232 N/V
Tx, Ty, Tz	8 lbf-in/V	16 lbf-in/V	32 lbf-in/V	1 Nm/V	2 Nm/V	4 Nm/V
±10V Sensitivity						
Fx, Fy	3 lbf/V	6 lbf/V	12 lbf/V	14.5 N/V	29 N/V	58 N/V
Fz	6 lbf/V	12 lbf/V	24 lbf/V	29 N/V	58 N/V	116 N/V
Tx, Ty, Tz	4 lbf-in/V	8 lbf-in/V	16 lbf-in/V	0.5 Nm/V	1 Nm/V	2 Nm/V
Tool Transform Factor	0.009091 in/unit	0.009091 in/unit	0.009091 in/unit	0.21277 mm/unit	0.21277 mm/unit	0.21277 mm/unit

4.5.3 Mini45 Physical Properties

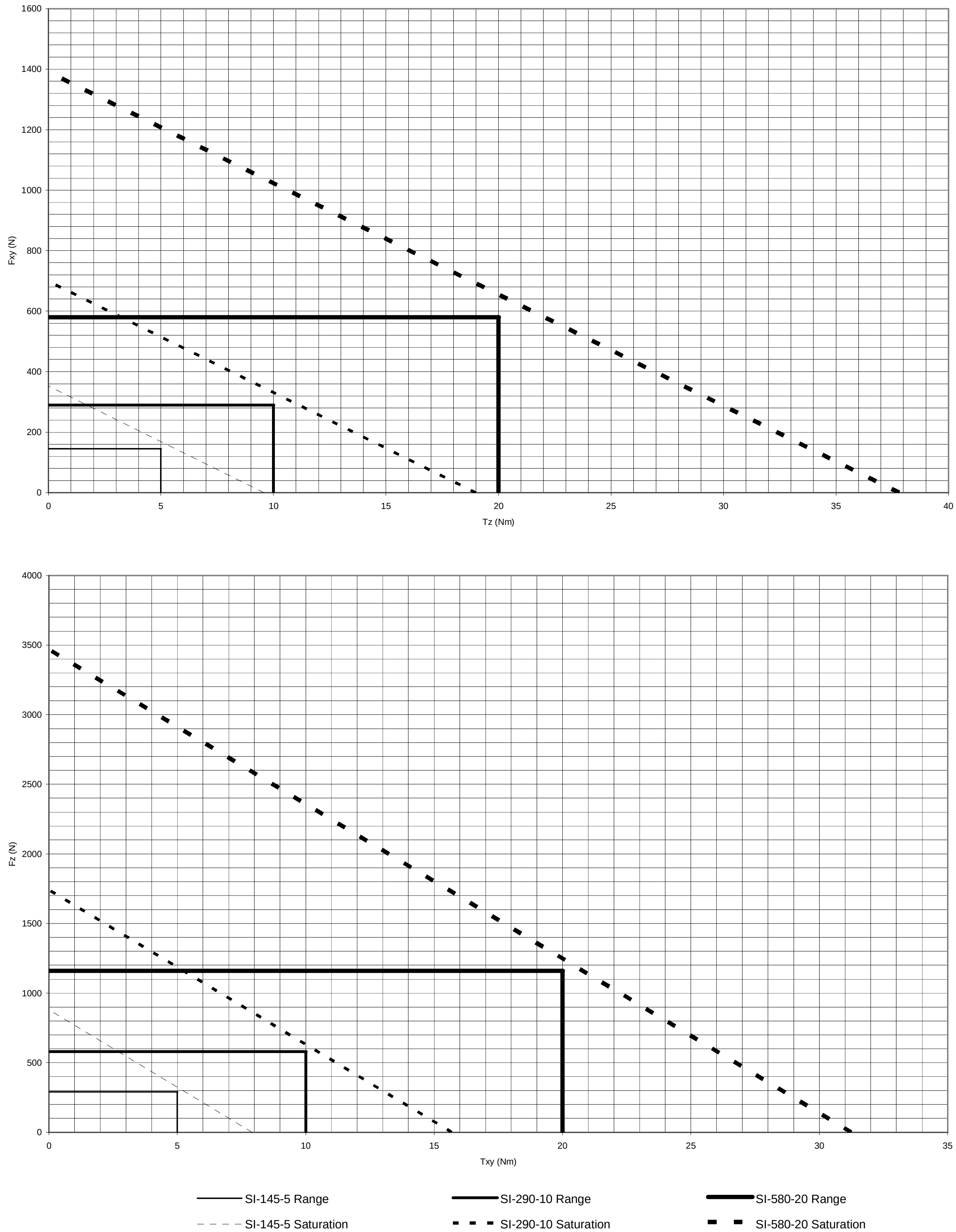
	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	420.E+3 lbf/in	74.E+6 N/m
Z-axis force (Kz)	560.E+3 lbf/in	98.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	150.E+3 in-lbf/rad	17.E+3 Nm/rad
Z-axis torque (Ktz)	310.E+3 in-lbf/rad	35.E+3 Nm/rad
Maximum Single-axis Load		
Fx, Fy	±1,100. lbf	±5,100. N
Fz	±2,300. lbf	±10,000. N
Tx, Ty, Tz	±1,000. lbf-in	±110. Nm
Tx, Ty, Tz	±1,200. lbf-in	±130. Nm
Weight (excluding cable)		
Transducer with standard aluminum plates	0.21 lb	95 g
Transducer with stainless steel plates	0.33 lb	148 g

4.5.4 Mini45 (US Calibration Complex Loading)

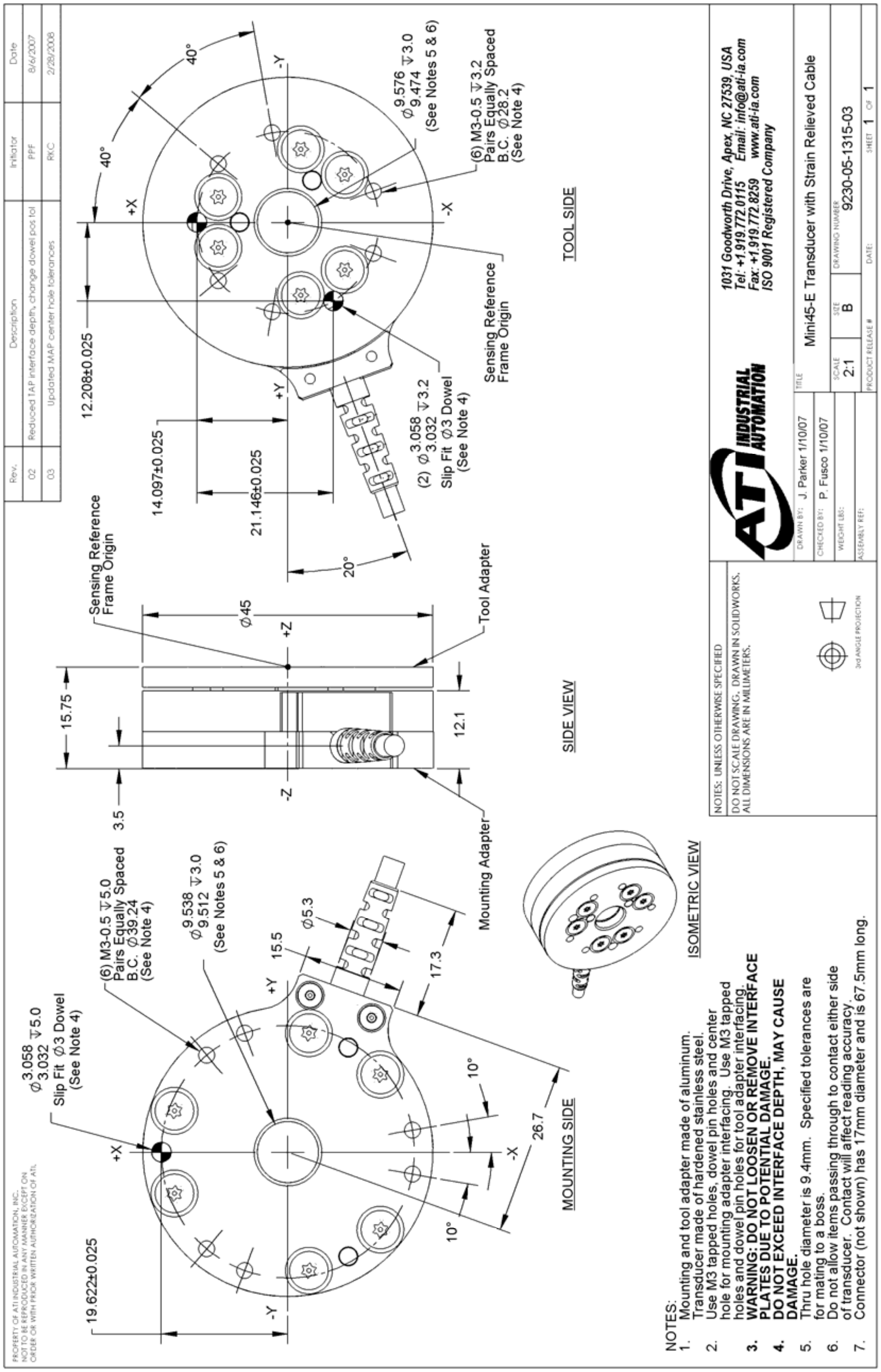




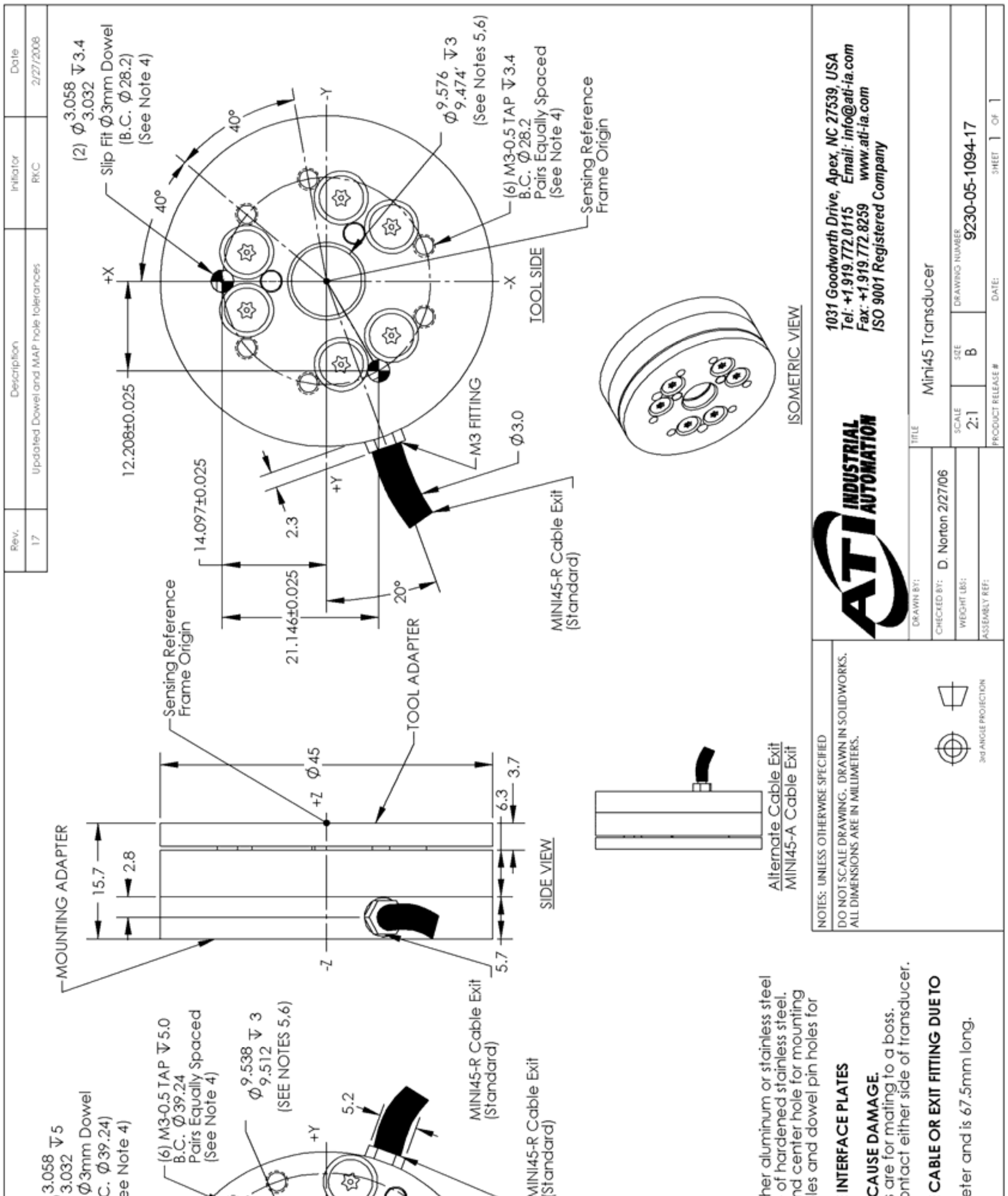
4.5.5 Mini45 (SI Calibration Complex Loading)



4.5.6 Mini45-E Transducer



4.5.7 Legacy Mini45 Transducer



4.6 Mini85

4.6.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-55-110**	**US-110-220**	**US-220-440**	**SI-250-12.5**	**SI-500-25**	**SI-1000-50**
Rated Sensing Ranges						
Fx, Fy	±55 lbf	±110 lbf	±220 lbf	±250 N	±500 N	±1000 N
Fz	±110 lbf	±220 lbf	±440 lbf	±500 N	±1000 N	±2000 N
Tx, Ty, Tz	±110 lbf-in	±220 lbf-in	±440 lbf-in	±12.5 Nm	±25 Nm	±50 Nm
Resolution (minimum)*						
Fx, Fy	7/640 lbf	7/320 lbf	7/160 lbf	7/144 N	7/72 N	7/36 N
Fz	1/64 lbf	1/32 lbf	1/16 lbf	5/72 N	5/36 N	5/18 N
Tx, Ty	3/160 lbf-in	3/80 lbf-in	3/40 lbf-in	7/3600 Nm	7/1800 Nm	7/900 Nm
Tz	1/64 lbf-in	1/32 lbf-in	1/16 lbf-in	1/600 Nm	1/300 Nm	1/150 Nm

*DAQ resolutions are typical for a 16-bit data acquisition system

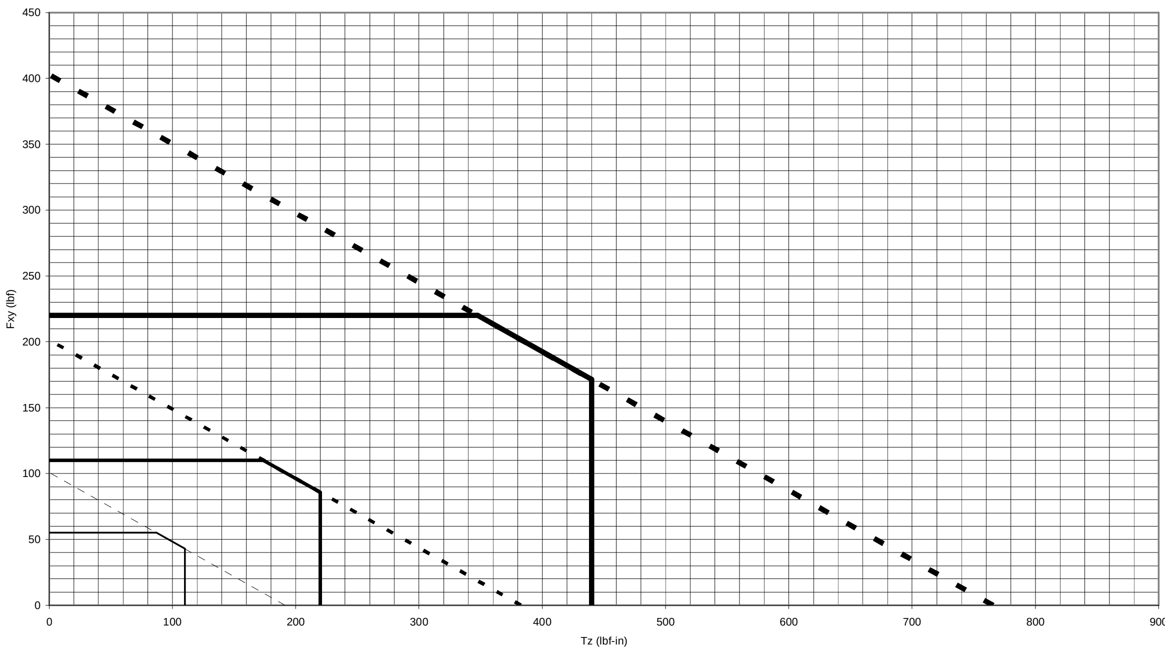
4.6.2 CTL Calibration Specifications

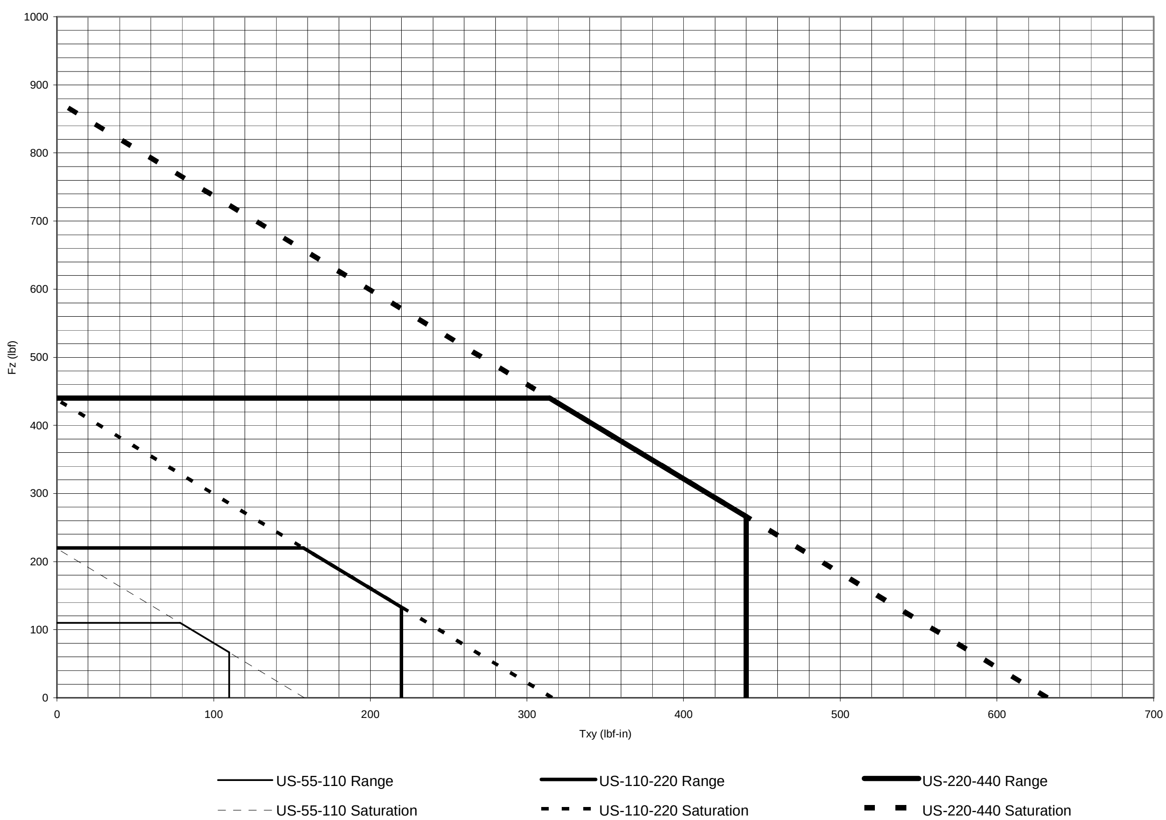
	US (English)			SI (Metric)		
Calibration	**US-55-110**	**US-110-220**	**US-220-440**	**SI-250-12.5**	**SI-500-25**	**SI-1000-50**
Rated Sensing Ranges						
Fx, Fy	±55 lbf	±110 lbf	±220 lbf	±250 N	±500 N	±1000 N
Fz	±110 lbf	±220 lbf	±440 lbf	±500 N	±1000 N	±2000 N
Tx, Ty, Tz	±110 lbf-in	±220 lbf-in	±440 lbf-in	±12.5 Nm	±25 Nm	±50 Nm
Resolution (minimum)						
Fx, Fy	7/320 lbf	7/160 lbf	7/80 lbf	7/72 N	7/36 N	7/18 N
Fz	1/32 lbf	1/16 lbf	1/8 lbf	5/36 N	5/18 N	5/9 N
Tx, Ty	3/80 lbf-in	3/40 lbf-in	3/20 lbf-in	7/1800 Nm	7/900 Nm	7/450 Nm
Tz	1/32 lbf-in	1/16 lbf-in	1/8 lbf-in	1/300 Nm	1/150 Nm	1/75 Nm
Counts Value						
Fx, Fy, Fz	2560 / lbf	1280 / lbf	640 / lbf	576 / N	288 / N	144 / N
Tx, Ty, Tz	1280 / lbf-in	640 / lbf-in	320 / lbf-in	14400 / Nm	7200 / Nm	3600 / Nm
Analog Output						
Analog Range						
Fx, Fy	±55 lbf	±110 lbf	±220 lbf	±250 N	±500 N	±1000 N
Fz	±110 lbf	±220 lbf	±440 lbf	±500 N	±1000 N	±2000 N
Tx, Ty, Tz	±110 lbf-in	±220 lbf-in	±440 lbf-in	±12.5 Nm	±25 Nm	±50 Nm
±5V Sensitivity						
Fx, Fy	11 lbf/V	22 lbf/V	44 lbf/V	50 N/V	100 N/V	200 N/V
Fz	22 lbf/V	44 lbf/V	88 lbf/V	100 N/V	200 N/V	400 N/V
Tx, Ty, Tz	22 lbf-in/V	44 lbf-in/V	88 lbf-in/V	2.5 Nm/V	5 Nm/V	10 Nm/V
±10V Sensitivity						
Fx, Fy	5.5 lbf/V	11 lbf/V	22 lbf/V	25 N/V	50 N/V	100 N/V
Fz	11 lbf/V	22 lbf/V	44 lbf/V	50 N/V	100 N/V	200 N/V
Tx, Ty, Tz	11 lbf-in/V	22 lbf-in/V	44 lbf-in/V	1.25 Nm/V	2.5 Nm/V	5 Nm/V
Tool Transform Factor	0.02 in/unit	0.02 in/unit	0.02 in/unit	0.4 mm/unit	0.4 mm/unit	0.4 mm/unit

4.6.3 Mini85 Physical Properties

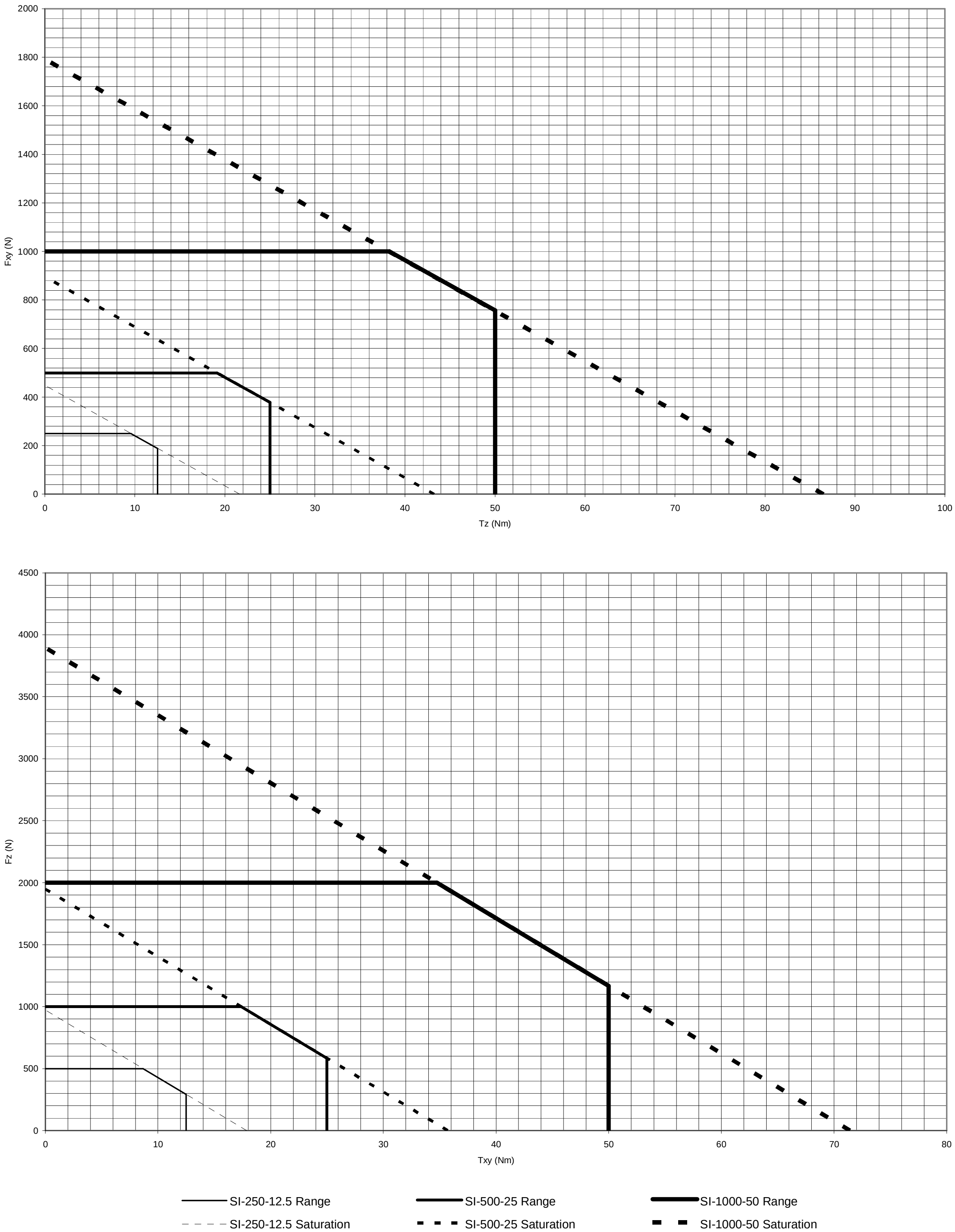
	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	440.E+3 lbf/in	77.E+6 N/m
Z-axis force (Kz)	680.E+3 lbf/in	120.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	720.E+3 in-lbf/rad	81.E+3 Nm/rad
Z-axis torque (Ktz)	1.2E+6 in-lbf/rad	130.E+3 Nm/rad
Resonance (Measured)		
Fx, Fy, Tz	3.1 kHz	
Fz, Tx, Ty	2.4 kHz	
Maximum Single-axis Load		
Fx, Fy	±2,800. lbf	±12,000. N
Fz	±6,100. lbf	±27,000. N
Tx, Ty, Tz	±4,400. lbf-in	±490. Nm
Tx, Ty, Tz	±5,300. lbf-in	±600. Nm
Weight (excluding cable)		
Transducer with standard aluminum plates	1.4 lb	635 g

4.6.4 Mini85 (US Calibration Complex Loading)

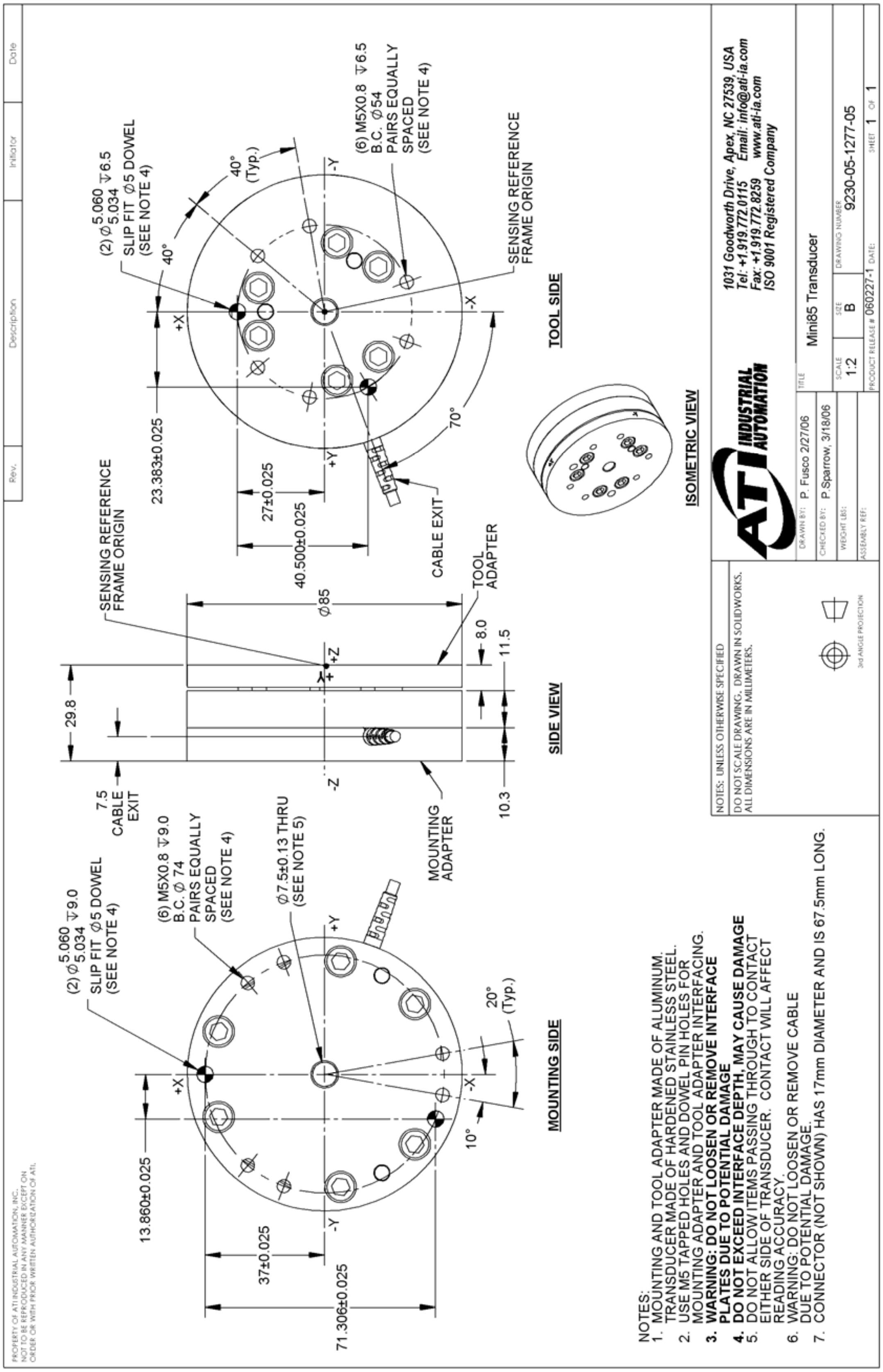




4.6.5 Mini85 (SI Calibration Complex Loading)



4.6.6 Mini85-E Transducer



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4.7 Gamma (Includes IP65 Version)

4.7.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-7.5-25**	**US-15-50**	**US-30-100**	**SI-32-2.5**	**SI-65-5**	**SI-130-10**
Rated Sensing Ranges						
Fx, Fy	±7.5 lbf	±15 lbf	±30 lbf	±32 N	±65 N	±130 N
Fz	±25 lbf	±50 lbf	±100 lbf	±100 N	±200 N	±400 N
Tx, Ty, Tz	±25 lbf-in	±50 lbf-in	±100 lbf-in	±2.5 Nm	±5 Nm	±10 Nm
Resolution (minimum)*						
Fx, Fy	1/640 lbf	1/320 lbf	1/160 lbf	1/160 N	1/80 N	1/40 N
Fz	1/320 lbf	1/160 lbf	1/80 lbf	1/80 N	1/40 N	1/20 N
Tx, Ty	3/640 lbf-in	1/160 lbf-in	1/80 lbf-in	1/2000 Nm	10/13333 Nm	1/800 Nm
Tz	1/320 lbf-in	1/160 lbf-in	1/80 lbf-in	1/2000 Nm	10/13333 Nm	1/800 Nm

*DAQ resolutions are typical for a 16-bit data acquisition system

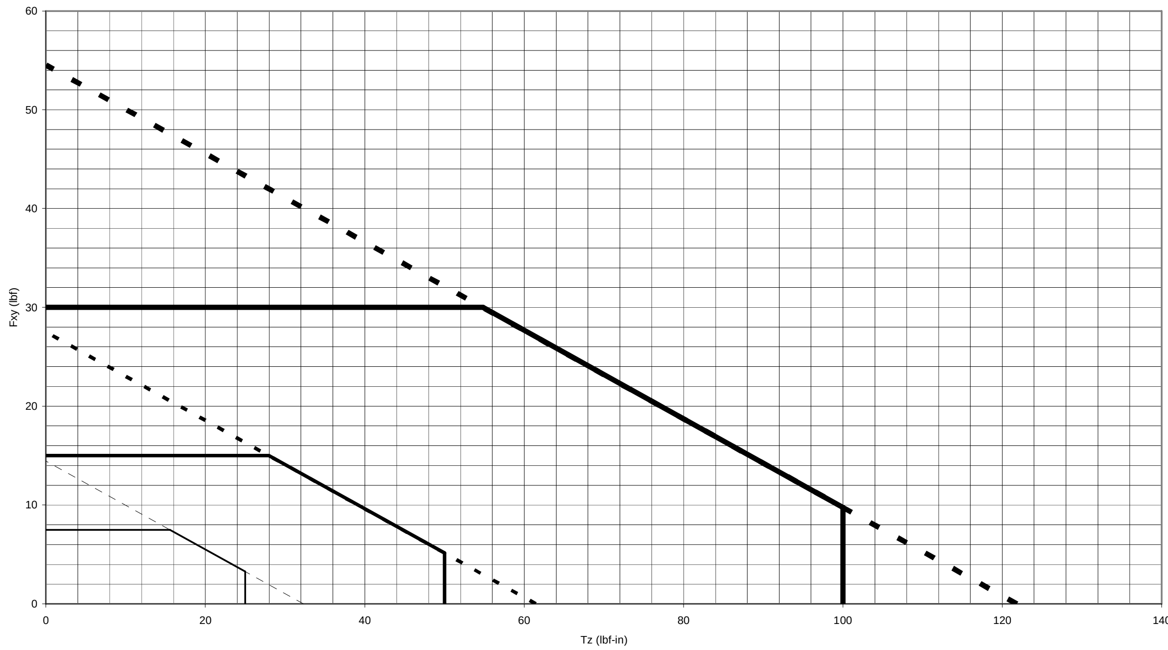
4.7.2 CTL Calibration Specifications

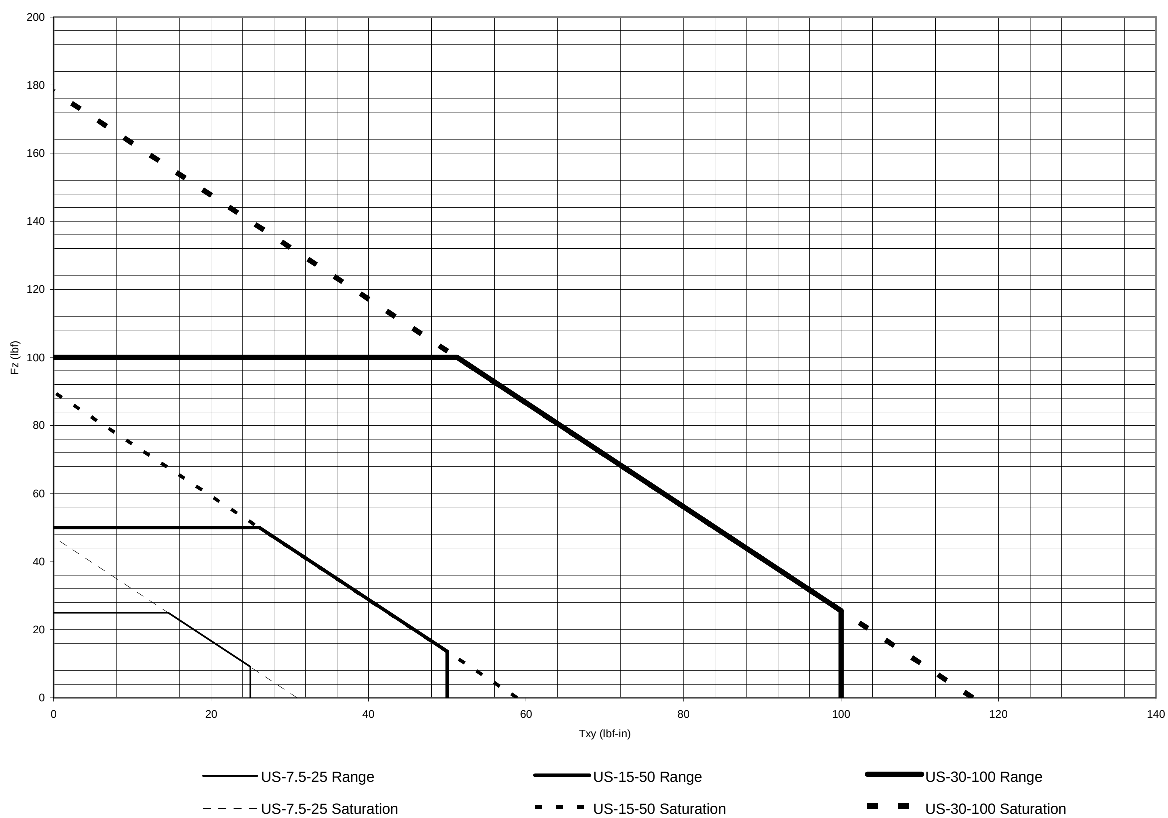
	US (English)			SI (Metric)		
Calibration	**US-7.5-25**	**US-15-50**	**US-30-100**	**SI-32-2.5**	**SI-65-5**	**SI-130-10**
Rated Sensing Ranges						
Fx, Fy	±7.5 lbf	±15 lbf	±30 lbf	±32 N	±65 N	±130 N
Fz	±25 lbf	±50 lbf	±100 lbf	±100 N	±200 N	±400 N
Tx, Ty, Tz	±25 lbf-in	±50 lbf-in	±100 lbf-in	±2.5 Nm	±5 Nm	±10 Nm
Resolution (minimum)						
Fx, Fy	1/320 lbf	1/160 lbf	1/80 lbf	1/80 N	1/40 N	1/20 N
Fz	1/160 lbf	1/80 lbf	1/40 lbf	1/40 N	1/20 N	1/10 N
Tx, Ty	3/320 lbf-in	1/80 lbf-in	1/40 lbf-in	1/1000 Nm	5/3333 Nm	1/400 Nm
Tz	1/160 lbf-in	1/80 lbf-in	1/40 lbf-in	1/1000 Nm	5/3333 Nm	1/400 Nm
Counts Value						
Fx, Fy, Fz	2560 / lbf	1280 / lbf	640 / lbf	640 / N	320 / N	160 / N
Tx, Ty, Tz	2560 / lbf-in	1280 / lbf-in	640 / lbf-in	8000 / Nm	5333.33 / Nm	3200 / Nm
Analog Output						
Analog Range						
Fx, Fy	±7.5 lbf	±15 lbf	±30 lbf	±32 N	±65 N	±130 N
Fz	±25 lbf	±50 lbf	±100 lbf	±100 N	±200 N	±400 N
Tx, Ty, Tz	±25 lbf-in	±50 lbf-in	±100 lbf-in	±2.5 Nm	±5 Nm	±10 Nm
±5V Sensitivity						
Fx, Fy	1.5 lbf/V	3 lbf/V	6 lbf/V	6.4 N/V	13 N/V	26 N/V
Fz	5 lbf/V	10 lbf/V	20 lbf/V	20 N/V	40 N/V	80 N/V
Tx, Ty, Tz	5 lbf-in/V	10 lbf-in/V	20 lbf-in/V	0.5 Nm/V	1 Nm/V	2 Nm/V
±10V Sensitivity						
Fx, Fy	0.75 lbf/V	1.5 lbf/V	3 lbf/V	3.2 N/V	6.5 N/V	13 N/V
Fz	2.5 lbf/V	5 lbf/V	10 lbf/V	10 N/V	20 N/V	40 N/V
Tx, Ty, Tz	2.5 lbf-in/V	5 lbf-in/V	10 lbf-in/V	0.25 Nm/V	0.5 Nm/V	1 Nm/V
Tool Transform Factor	0.01 in/unit	0.01 in/unit	0.01 in/unit	0.8 mm/unit	0.6 mm/unit	0.5 mm/unit

4.7.3 Gamma Physical Properties (Includes IP65 Version)

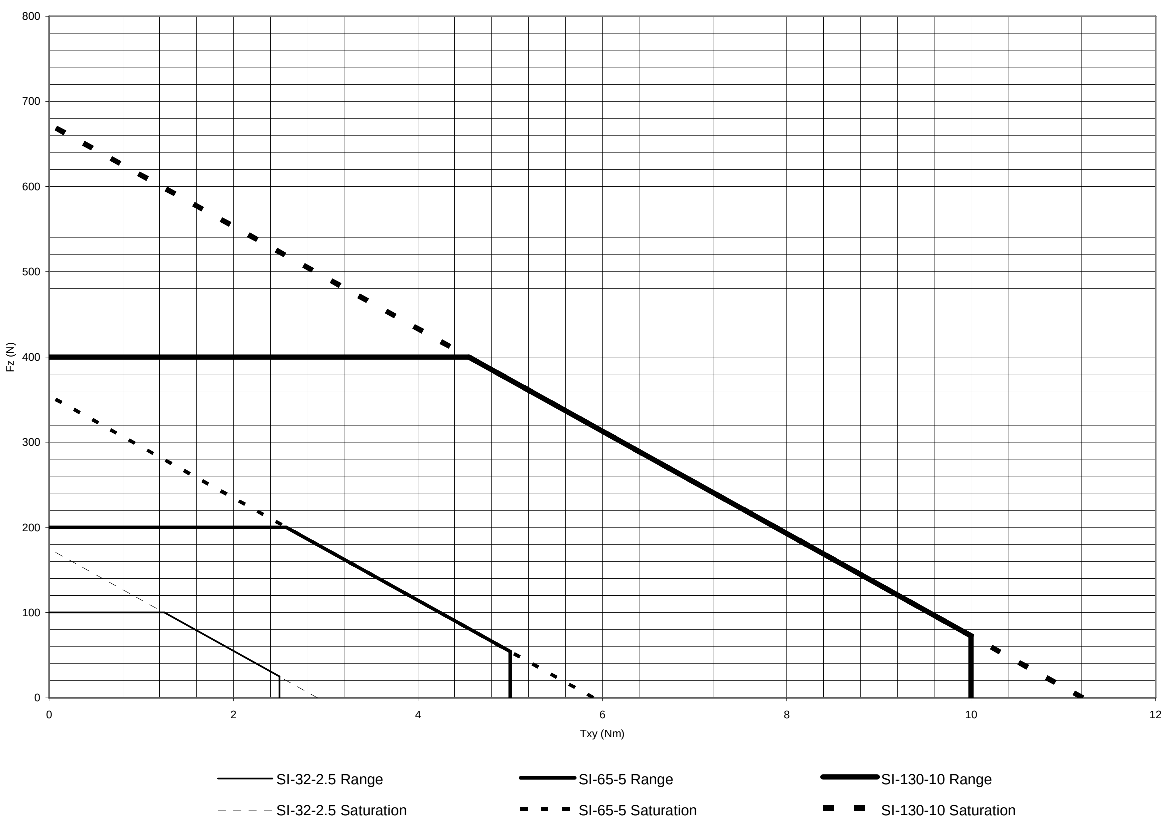
	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	51.E+3 lbf/in	8.9E+6 N/m
Z-axis force (Kz)	92.E+3 lbf/in	16.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	86.E+3 in-lbf/rad	9.7E+3 Nm/rad
Z-axis torque (Ktz)	140.E+3 in-lbf/rad	16.E+3 Nm/rad
Resonance (Measured, non-IP Version)		
Fx, Fy, Tz	2.0 kHz	
Fz, Tx, Ty	1.4 kHz	
Resonance (Measured, IP65/68 Version)		
Fx, Fy, Tz	1.0 kHz	
Fz, Tx, Ty	970 Hz	
Maximum Single-axis Load		
Fx, Fy	±230. lbf	±1,000. N
Fz	±730. lbf	±3,200. N
Tx, Ty	±610. lbf-in	±69. Nm
Tz	±720. lbf-in	±82. Nm
Weight (excluding cable)		
Transducer with standard aluminum MAP plates	0.56 lb	250 g
Transducer with ring/plug TAP	0.75 lb	325 g
Transducer with ring/plug MAP	0.8 lb	375 g
Transducer with ring/plug TAP and MAP	0.99 lb	450 g
IP65	2.4 lb	1.1 kg

4.7.4 Gamma (US Calibration Complex Loading) (Includes IP65 Version)

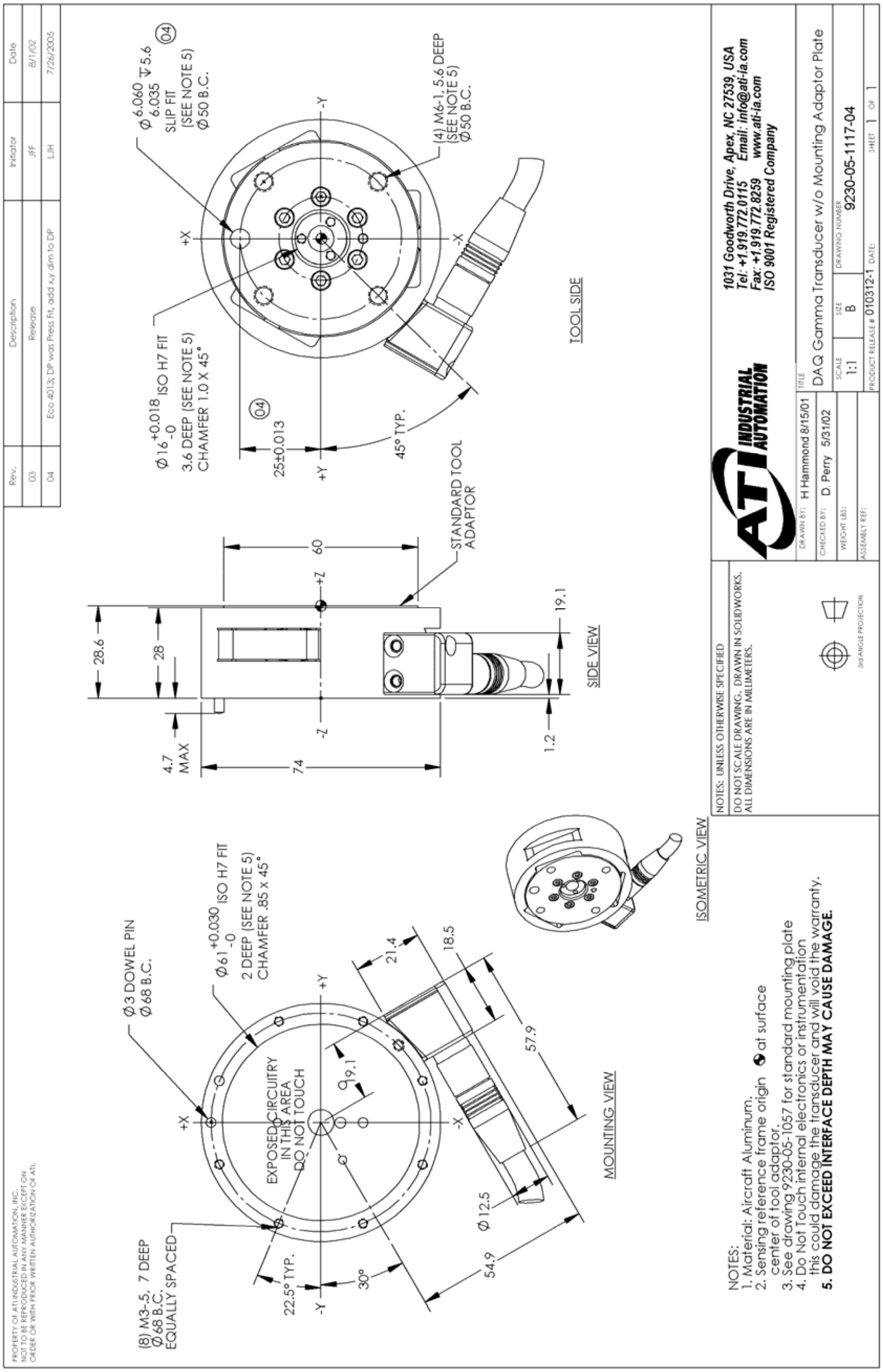




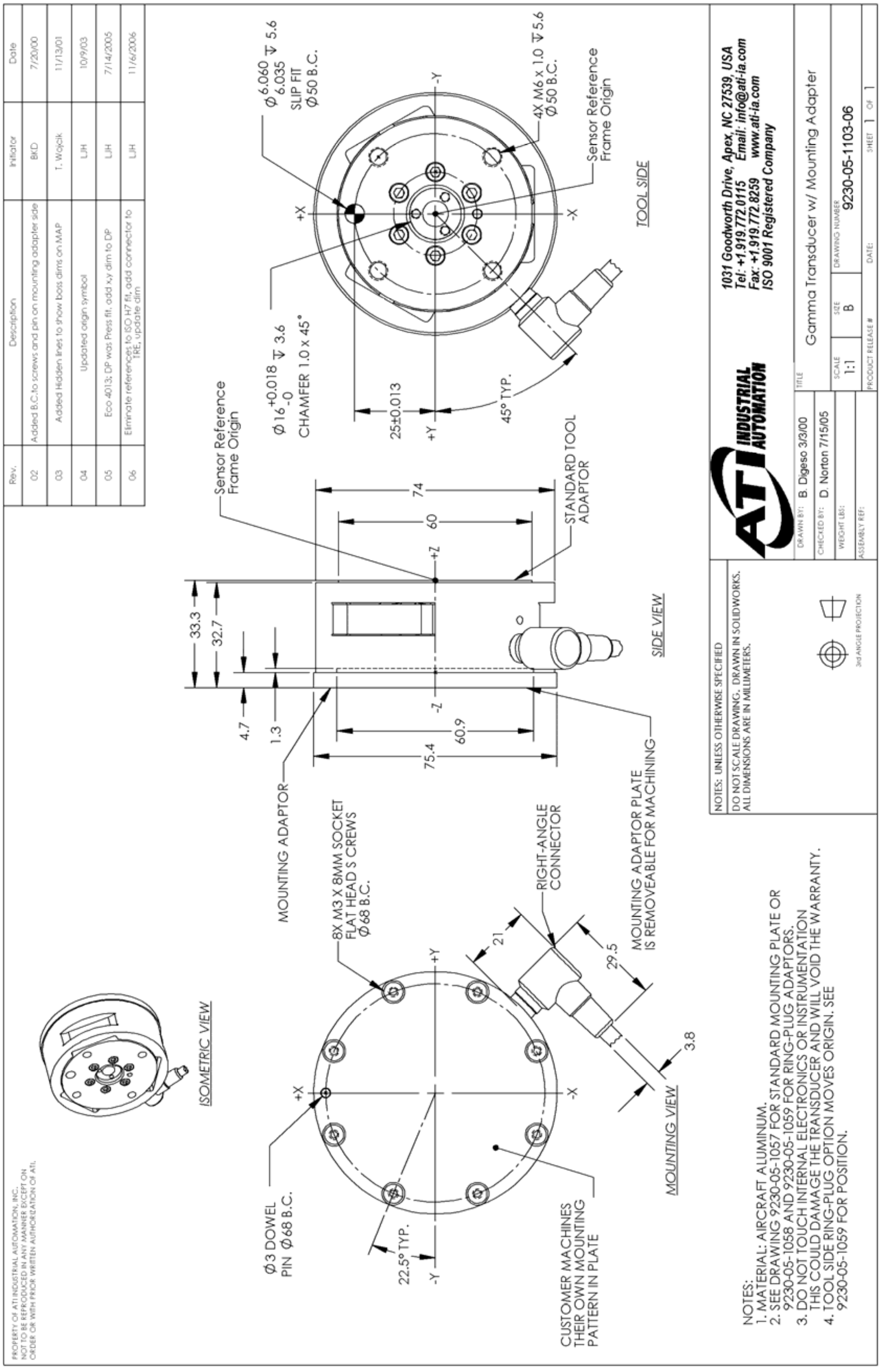
4.7.5 Gamma (SI Calibration Complex Loading) (Includes IP65 Version)



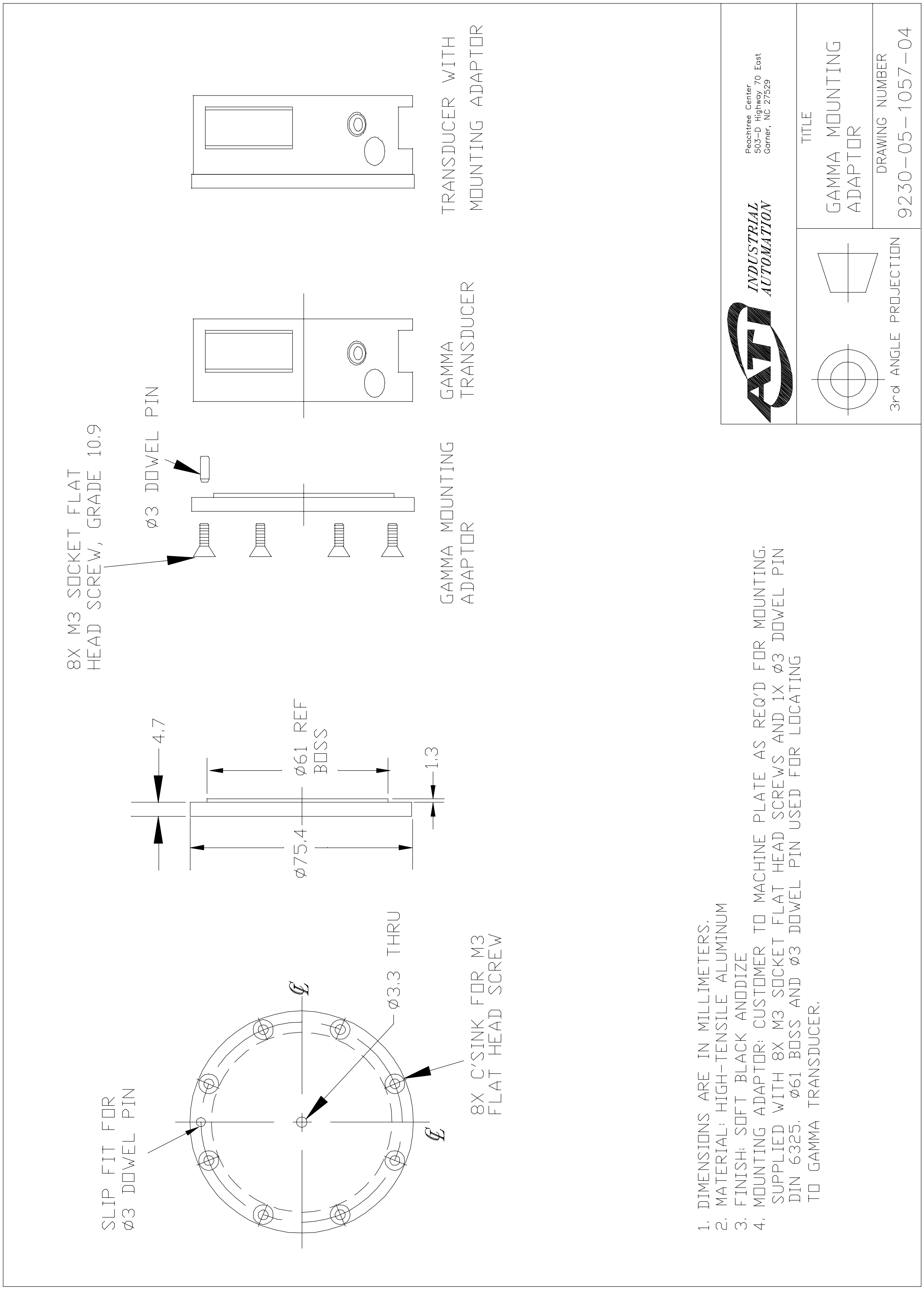
4.7.6 Gamma DAQ Transducer with Mounting Adapter



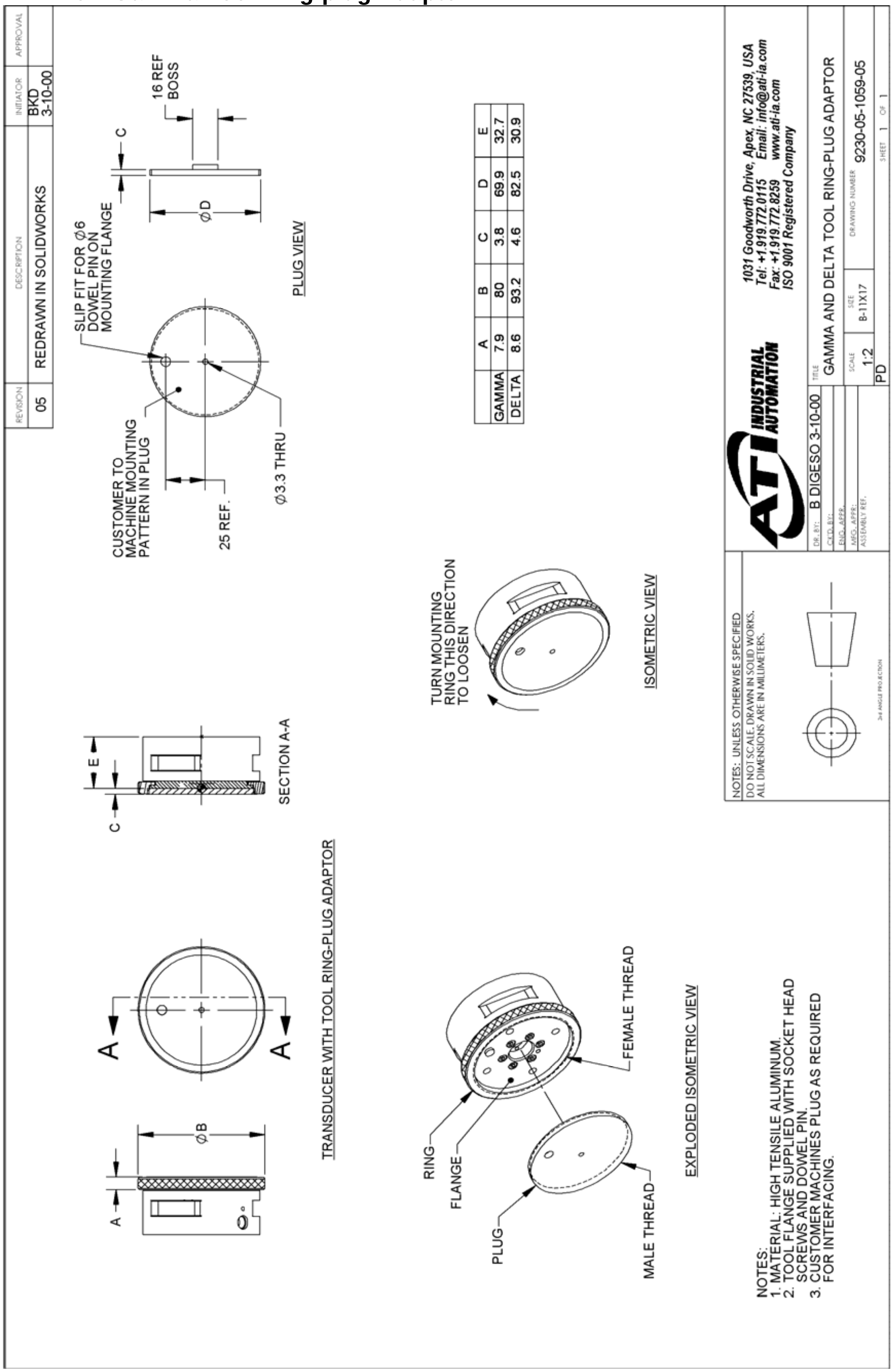
4.7.7 Gamma Mux Transducer with Mounting Adapter



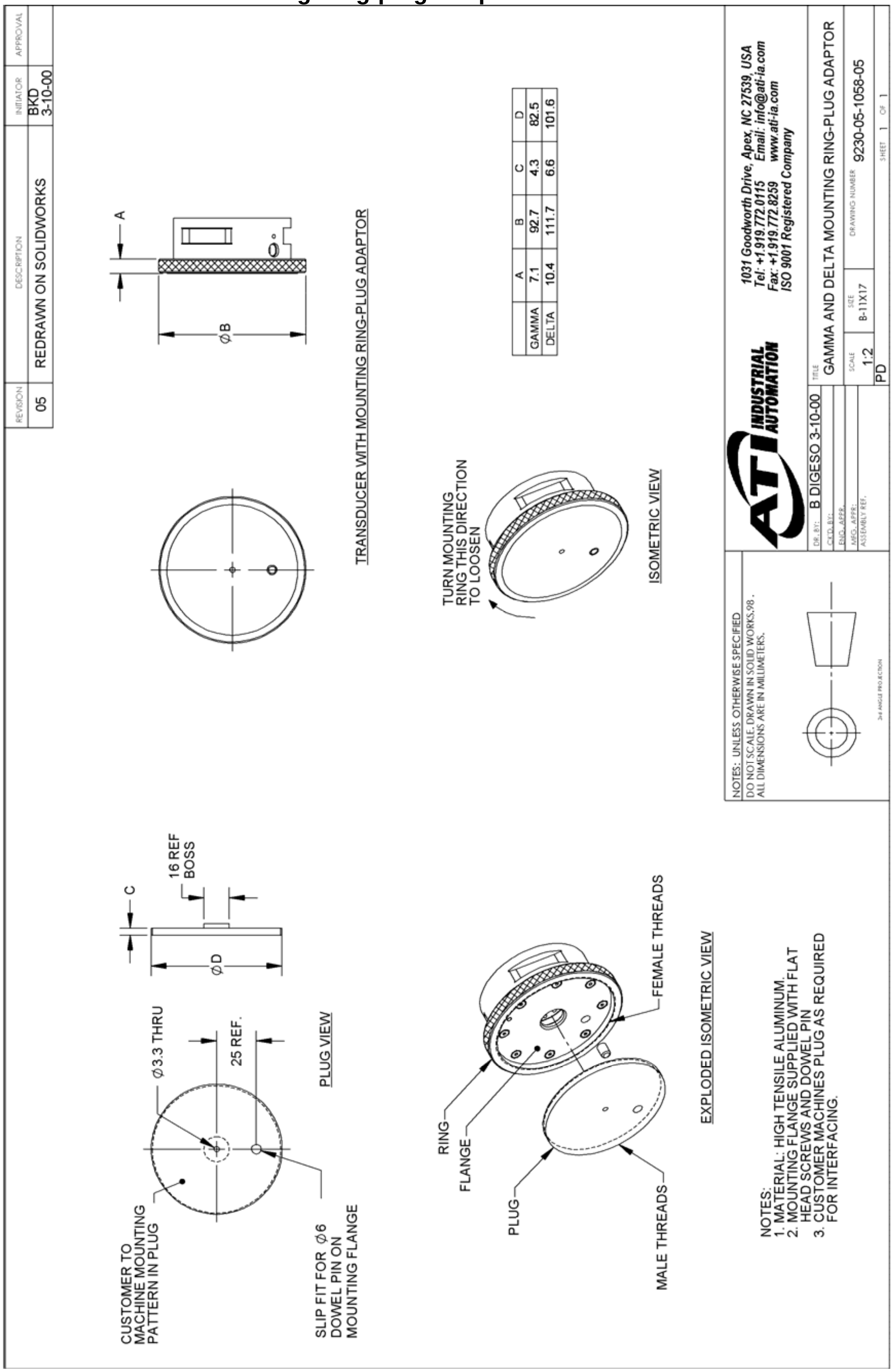
4.7.8 Gamma Mounting Adapter Plate



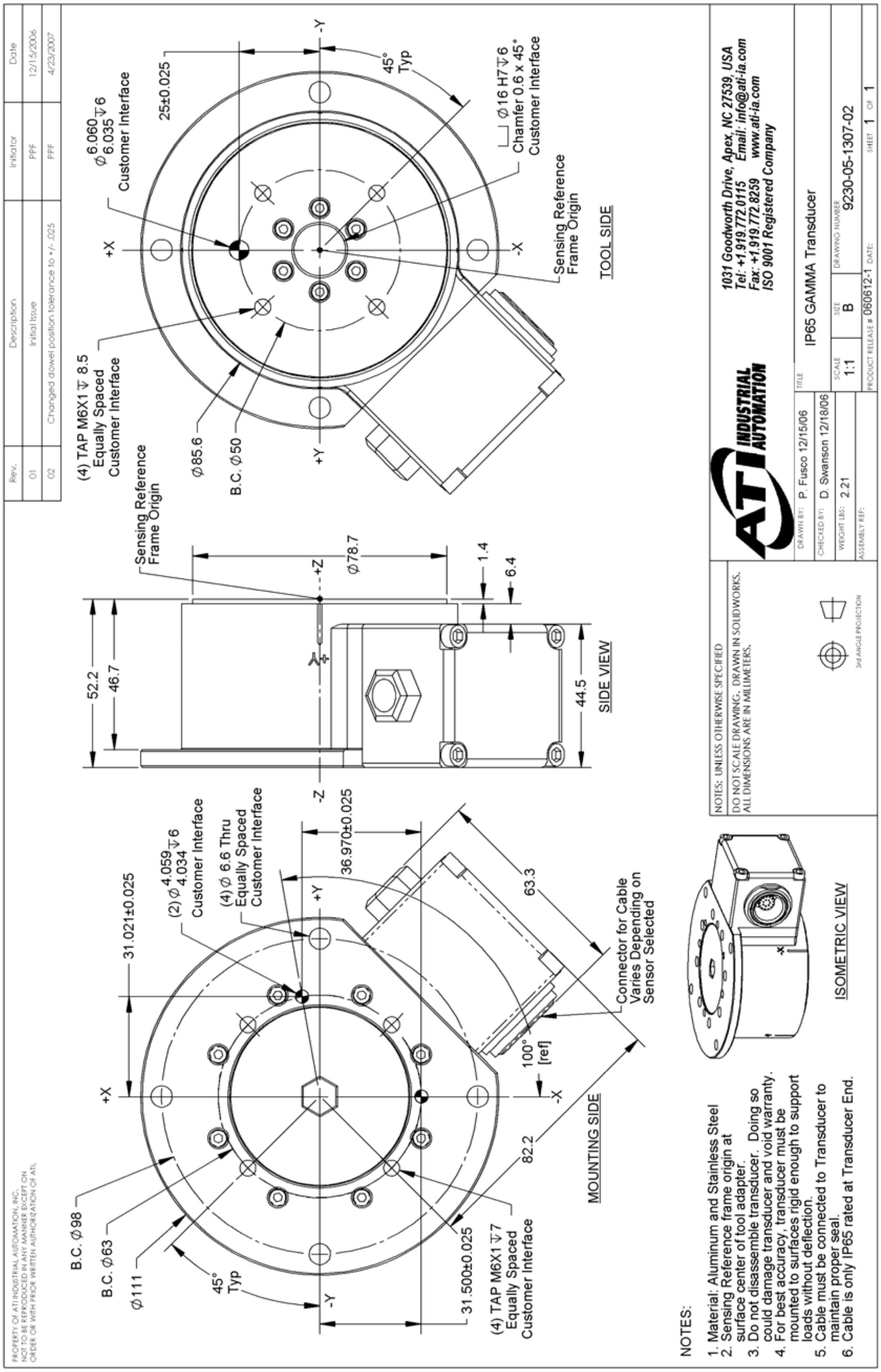
4.7.9 Gamma Tool Ring-plug Adapter



4.7.10 Gamma Mounting Ring-plug Adapter



4.7.11 IP65 Rated Gamma Transducer



4.8 Delta (Includes IP60/IP65/IP68 Versions)

4.8.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			**SI (Metric)**		
Calibration	**US-50-150**	**US-75-300**	**US-150-600**	**SI-165-15**	**SI-330-30**	**SI-660-60**
Rated Sensing Ranges						
Fx, Fy	±50 lbf	±75 lbf	±150 lbf	±165 N	±330 N	±660 N
Fz**	±150 lbf	±225 lbf	±450 lbf	±495 N	±990 N	±1980 N
Tx, Ty, Tz	±150 lbf-in	±300 lbf-in	±600 lbf-in	±15 Nm	±30 Nm	±60 Nm
Resolution (minimum)*						
Fx, Fy	1/128 lbf	1/64 lbf	1/32 lbf	1/32 N	1/16 N	1/8 N
Fz	1/64 lbf	1/32 lbf	1/16 lbf	1/16 N	1/8 N	1/4 N
Tx, Ty	3/128 lbf-in	3/64 lbf-in	3/32 lbf-in	1/528 Nm	5/1333 Nm	10/1333 Nm
Tz	1/64 lbf-in	1/32 lbf-in	1/16 lbf-in	1/528 Nm	5/1333 Nm	10/1333 Nm

*DAQ resolutions are typical for a 16-bit data acquisition system

4.8.2 CTL Calibration Specifications

	US (English)			**SI (Metric)**		
Calibration	**US-50-150**	**US-75-300**	**US-150-600**	**SI-165-15**	**SI-330-30**	**SI-660-60**
Rated Sensing Ranges						
Fx, Fy	±50 lbf	±75 lbf	±150 lbf	±165 N	±330 N	±660 N
Fz**	±150 lbf	±225 lbf	±450 lbf	±495 N	±990 N	±1980 N
Tx, Ty, Tz	±150 lbf-in	±300 lbf-in	±600 lbf-in	±15 Nm	±30 Nm	±60 Nm
Resolution (minimum)						
Fx, Fy	1/64 lbf	1/32 lbf	1/16 lbf	1/16 N	1/8 N	1/4 N
Fz	1/32 lbf	1/16 lbf	1/8 lbf	1/8 N	1/4 N	1/2 N
Tx, Ty	3/64 lbf-in	3/32 lbf-in	3/16 lbf-in	1/264 Nm	10/1333 Nm	5/333 Nm
Tz	1/32 lbf-in	1/16 lbf-in	1/8 lbf-in	1/264 Nm	10/1333 Nm	5/333 Nm
Counts Value						
Fx, Fy, Fz	512 / lbf	256 / lbf	128 / lbf	128 / N	64 / N	32 / N
Tx, Ty, Tz	512 / lbf-in	256 / lbf-in	128 / lbf-in	2112 / Nm	1066.67 / Nm	533.333 / Nm
Analog Output						
Analog Range						
Fx, Fy	±50 lbf	±75 lbf	±150 lbf	±165 N	±330 N	±660 N
Fz**	±150 lbf	±225 lbf	±450 lbf	±495 N	±990 N	±1980 N
Tx, Ty, Tz	±150 lbf-in	±300 lbf-in	±600 lbf-in	±15 Nm	±30 Nm	±60 Nm
±5V Sensitivity						
Fx, Fy	10 lbf/V	15 lbf/V	30 lbf/V	33 N/V	66 N/V	132 N/V
Fz	30 lbf/V	45 lbf/V	90 lbf/V	99 N/V	198 N/V	396 N/V
Tx, Ty, Tz	30 lbf-in/V	60 lbf-in/V	120 lbf-in/V	3 Nm/V	6 Nm/V	12 Nm/V
±10V Sensitivity						
Fx, Fy	5 lbf/V	7.5 lbf/V	15 lbf/V	16.5 N/V	33 N/V	66 N/V
Fz	15 lbf/V	22.5 lbf/V	45 lbf/V	49.5 N/V	99 N/V	198 N/V
Tx, Ty, Tz	15 lbf-in/V	30 lbf-in/V	60 lbf-in/V	1.5 Nm/V	3 Nm/V	6 Nm/V
Tool Transform Factor	0.01 in/unit	0.01 in/unit	0.01 in/unit	0.6061 mm/unit	0.6 mm/unit	0.6 mm/unit

**For IP68 version see caution on physical properties page.

4.8.3 Delta Physical Properties (Includes IP60/IP65/IP68 Versions)

	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	180.E+3 lbf/in	32.E+6 N/m
Z-axis force (Kz)	220.E+3 lbf/in	39.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	330.E+3 in-lbf/rad	38.E+3 Nm/rad
Z-axis torque (Ktz)	760.E+3 in-lbf/rad	86.E+3 Nm/rad
Resonance (Measured, non-IP Version)		
Fx, Fy, Tz	1.7 kHz	
Fz, Tx, Ty	1.5 kHz	
Resonance (Measured, IP60 Version)		
Fx, Fy, Tz	1.1 kHz	
Fz, Tx, Ty	1.1 kHz	
Resonance (Measured, IP65/68 Version)		
Fx, Fy, Tz	880 Hz	
Fz, Tx, Ty	920 Hz	
Maximum Single-axis Load		
Fx, Fy	±290. lbf	±1,300. N
Fz	±1,400. lbf	±6,200. N
Tx, Ty	±950. lbf-in	±100. Nm
Tz	±3,900. lbf-in	±440. Nm
Weight		
Standard Delta		
Transducer with standard aluminum MAP plates	2.0 lb	907 g
Transducer with ring/plug TAP	2.6 lb	1179 g
Transducer with ring/plug MAP	2.7 lb	1225 g
IP60	4.0 lb	1.8 kg
IP65/IP68	5.8 lb	2.6 kg

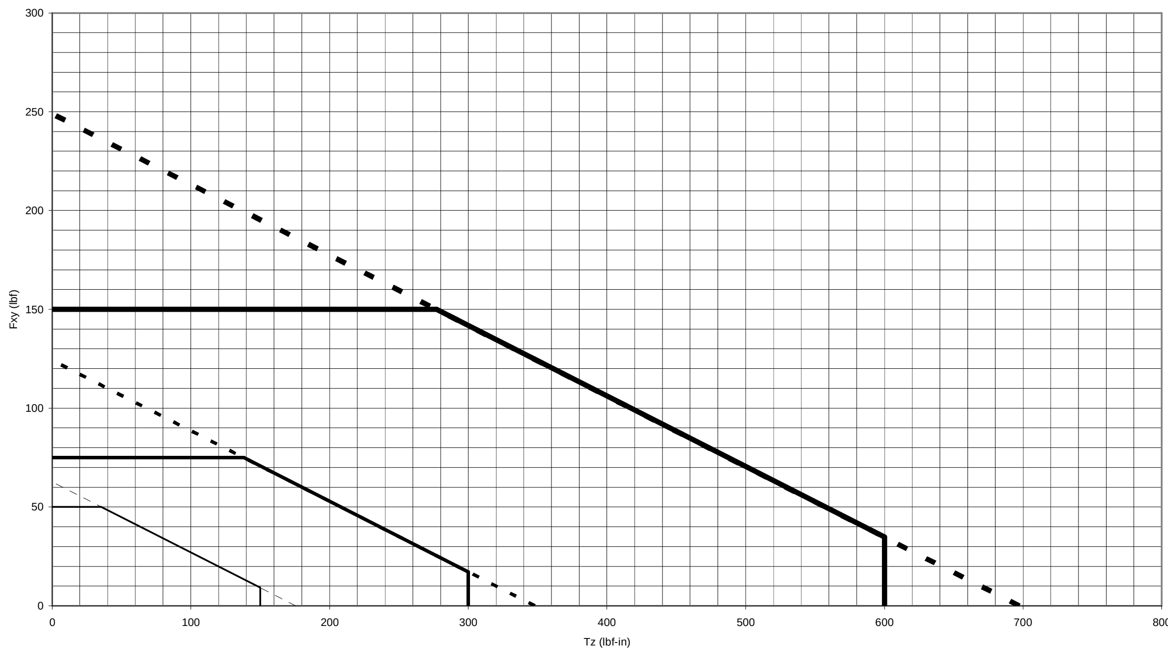
CAUTION:

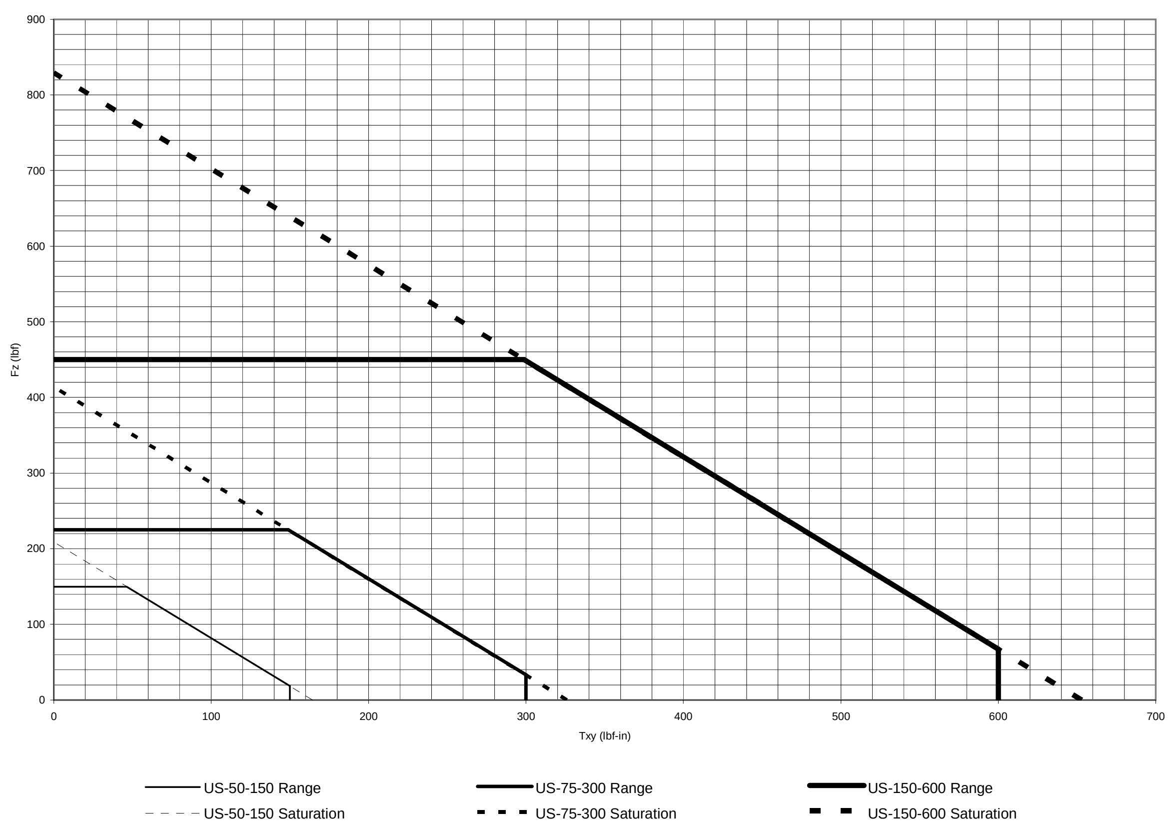
IP68 Delta Fz as a Function of Submersion Depth:

When submerged, IP68 transducers exhibit a decrease in Fz range related to the submersion depth. This loss is the result of pressure-induced preloading on the transducer. The preload can be masked by biasing the transducer at the depth prior to applying the load to be measured. The following estimates are for room temperature fresh water at seal level.

IP68 Delta	US	Metric
Fz preload at 10m depth	- 161 lb	- 716 N
Fz preload at other depths	- 4.9 lb/ft x depthInFeet	- 72 N/m x depthInMeters

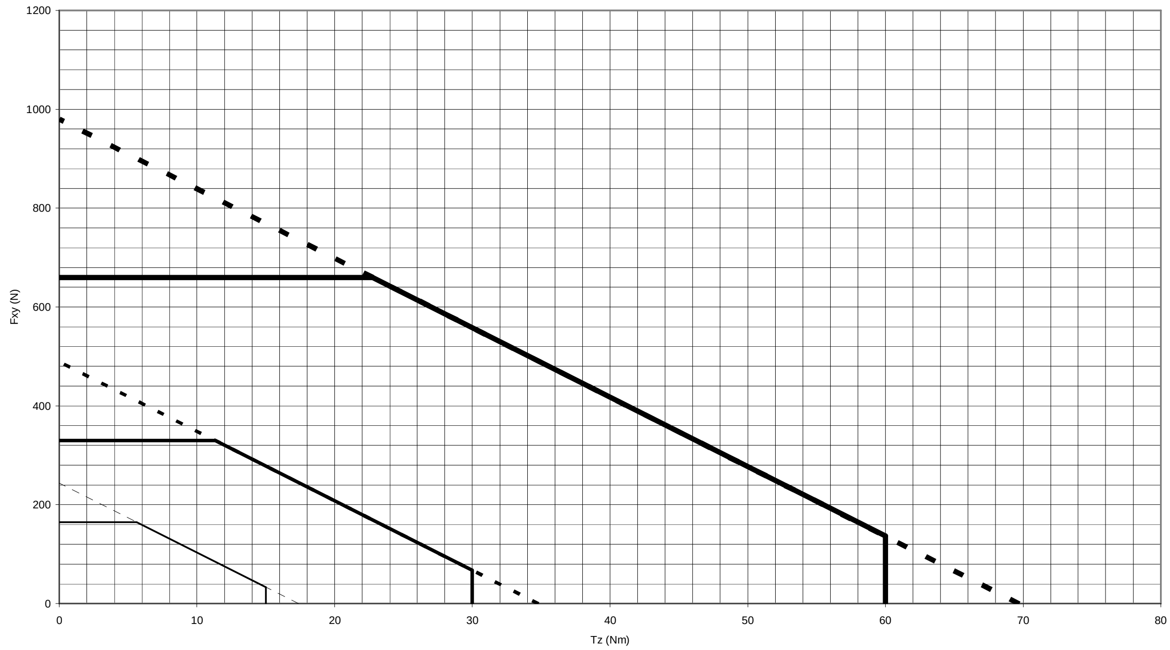
4.8.4 Delta (US Calibration Complex Loading) (Includes IP60/IP65/IP68 Versions)

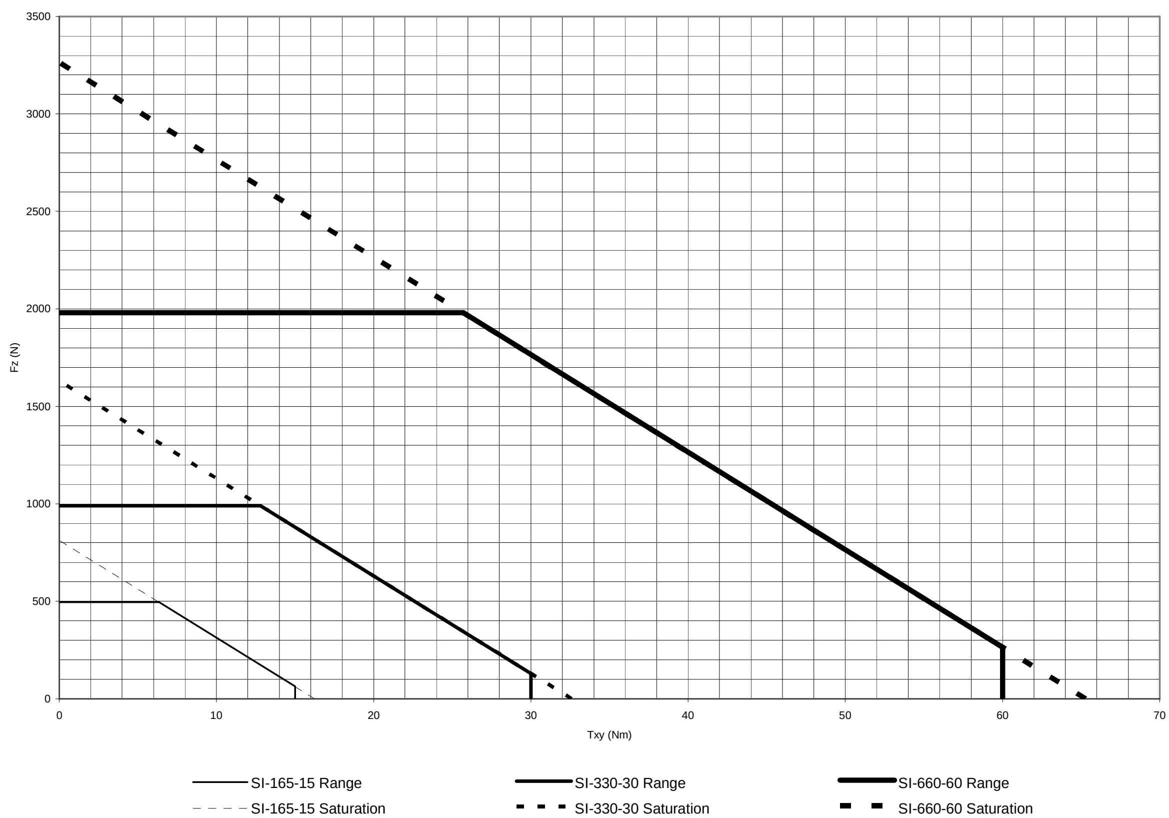




** For IP68 version see caution on physical properties page.

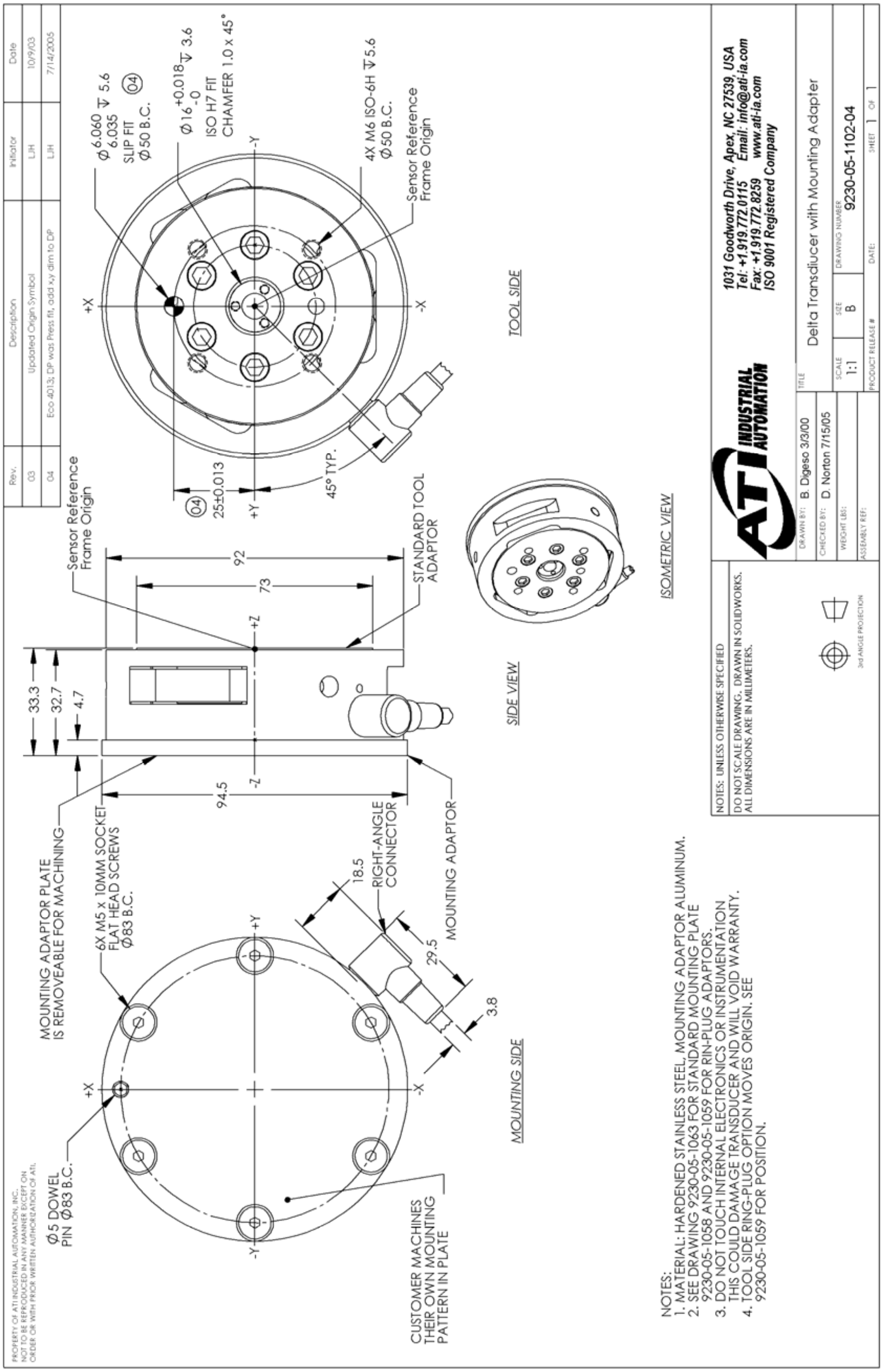
4.8.5 Delta (SI Calibration Complex Loading) (Includes IP60/IP65/IP68 Versions)



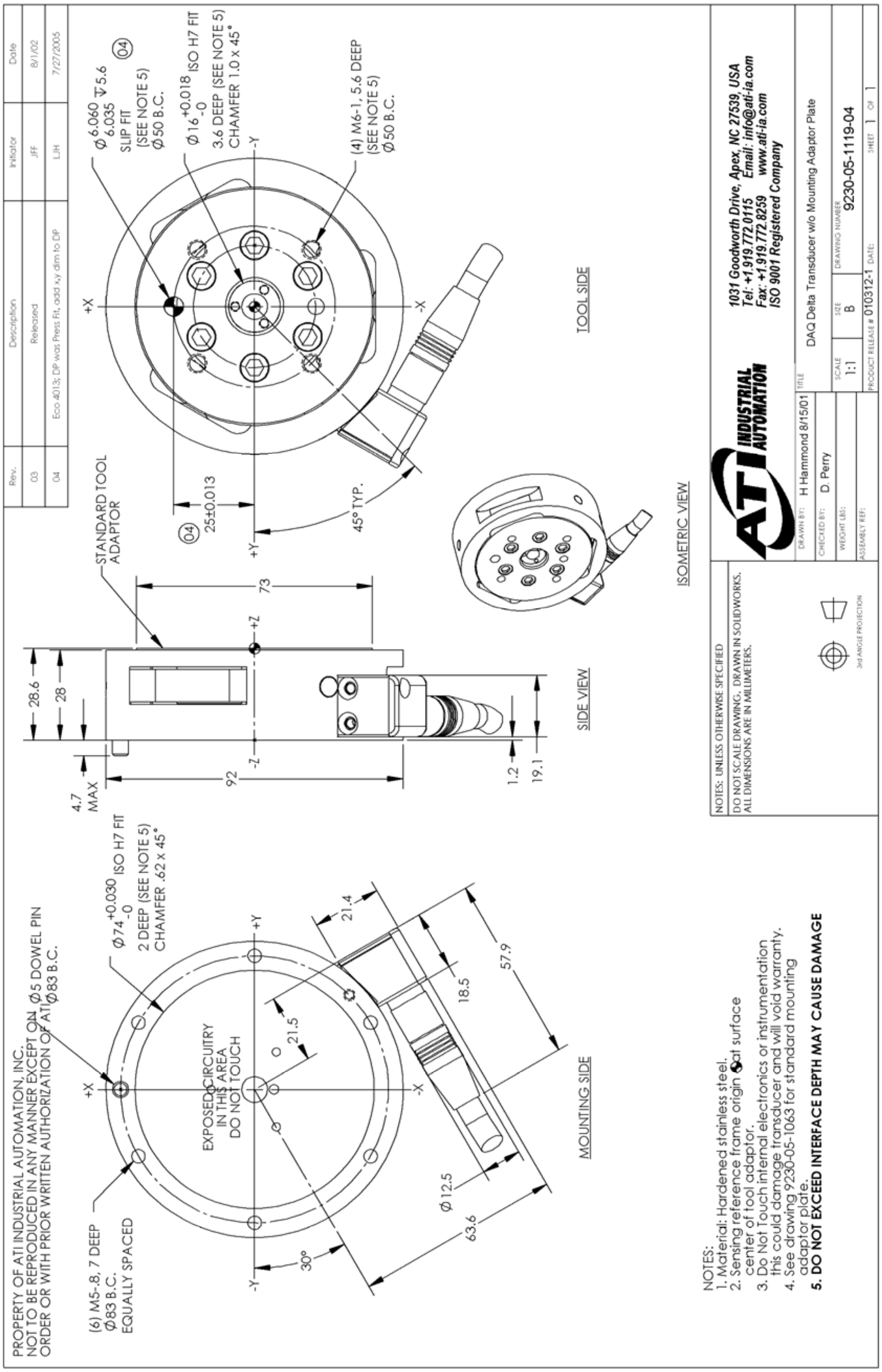


** For IP68 version see caution on physical properties page.

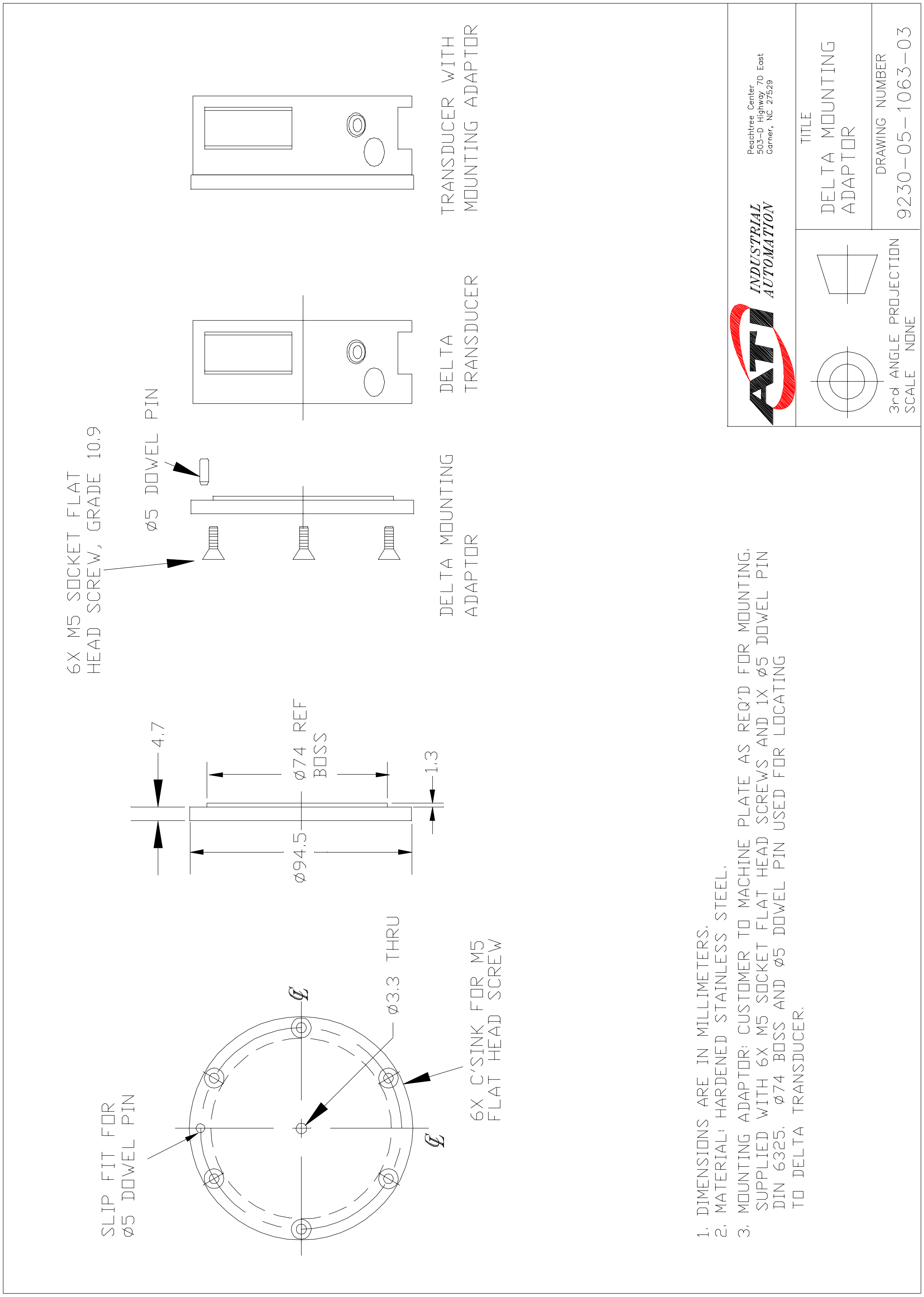
4.8.6 Delta Transducer with Mounting Adapter



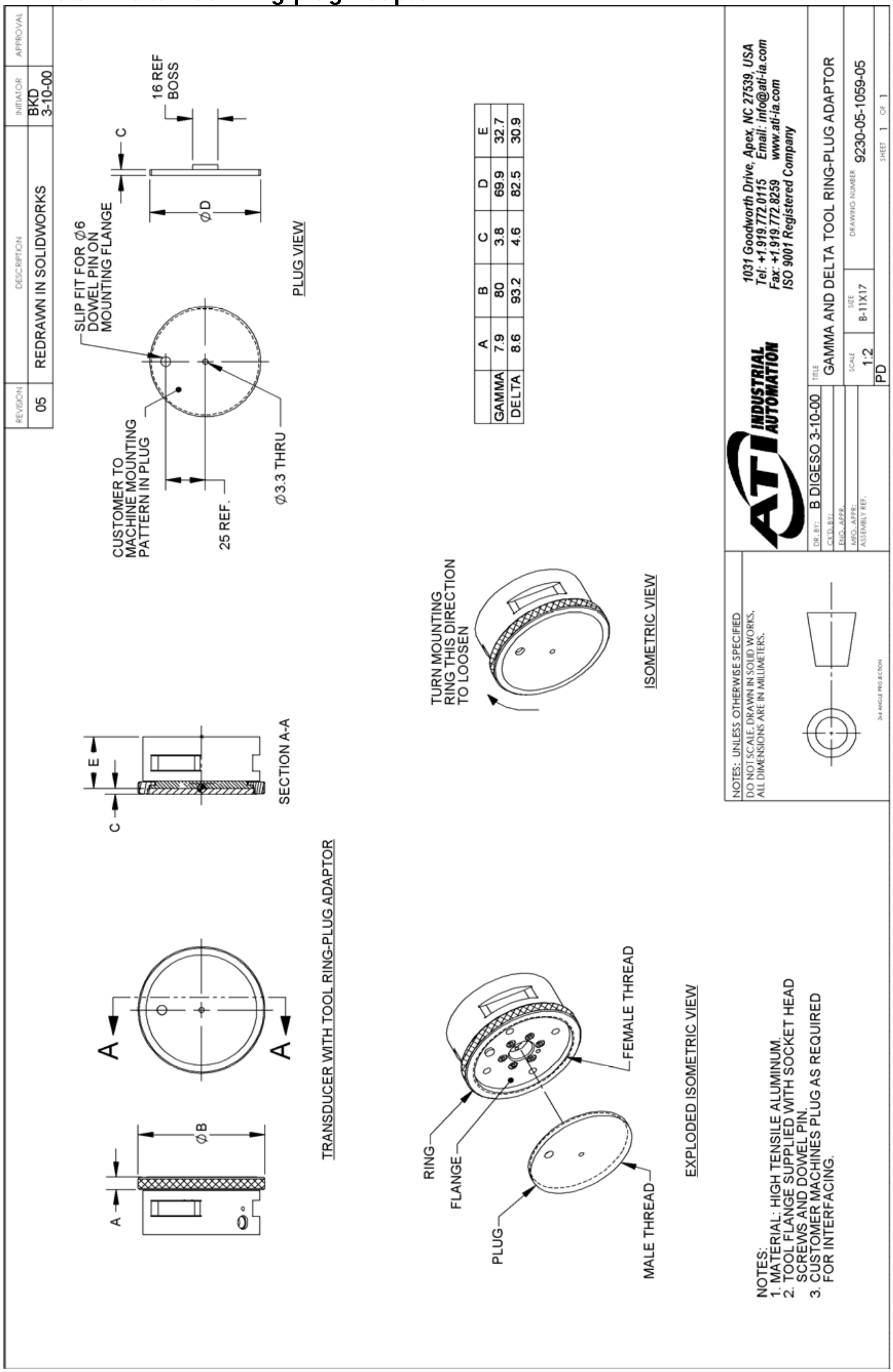
4.8.7 Delta DAQ Transducer



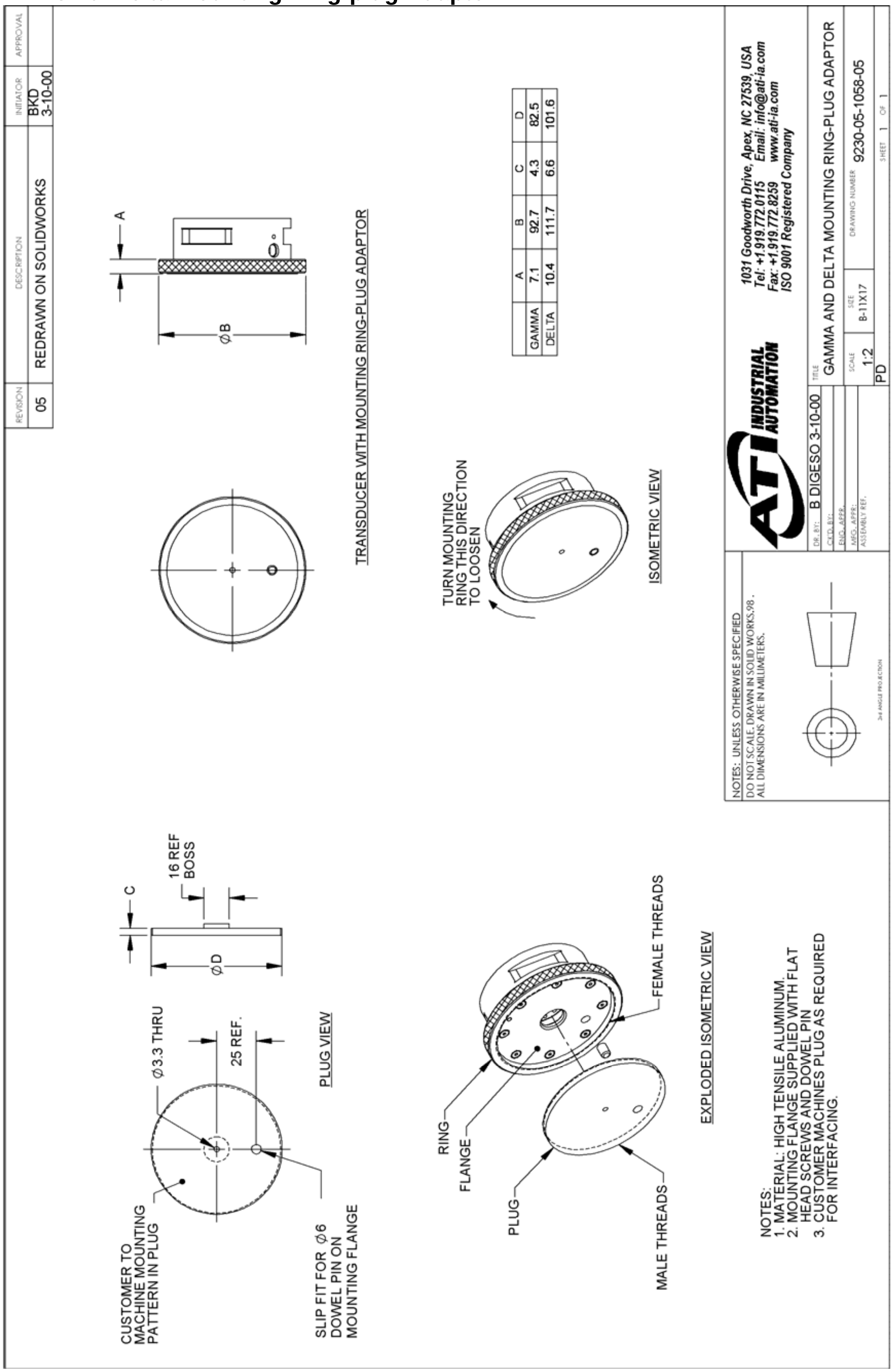
4.8.8 Delta Mounting Adapter Plate



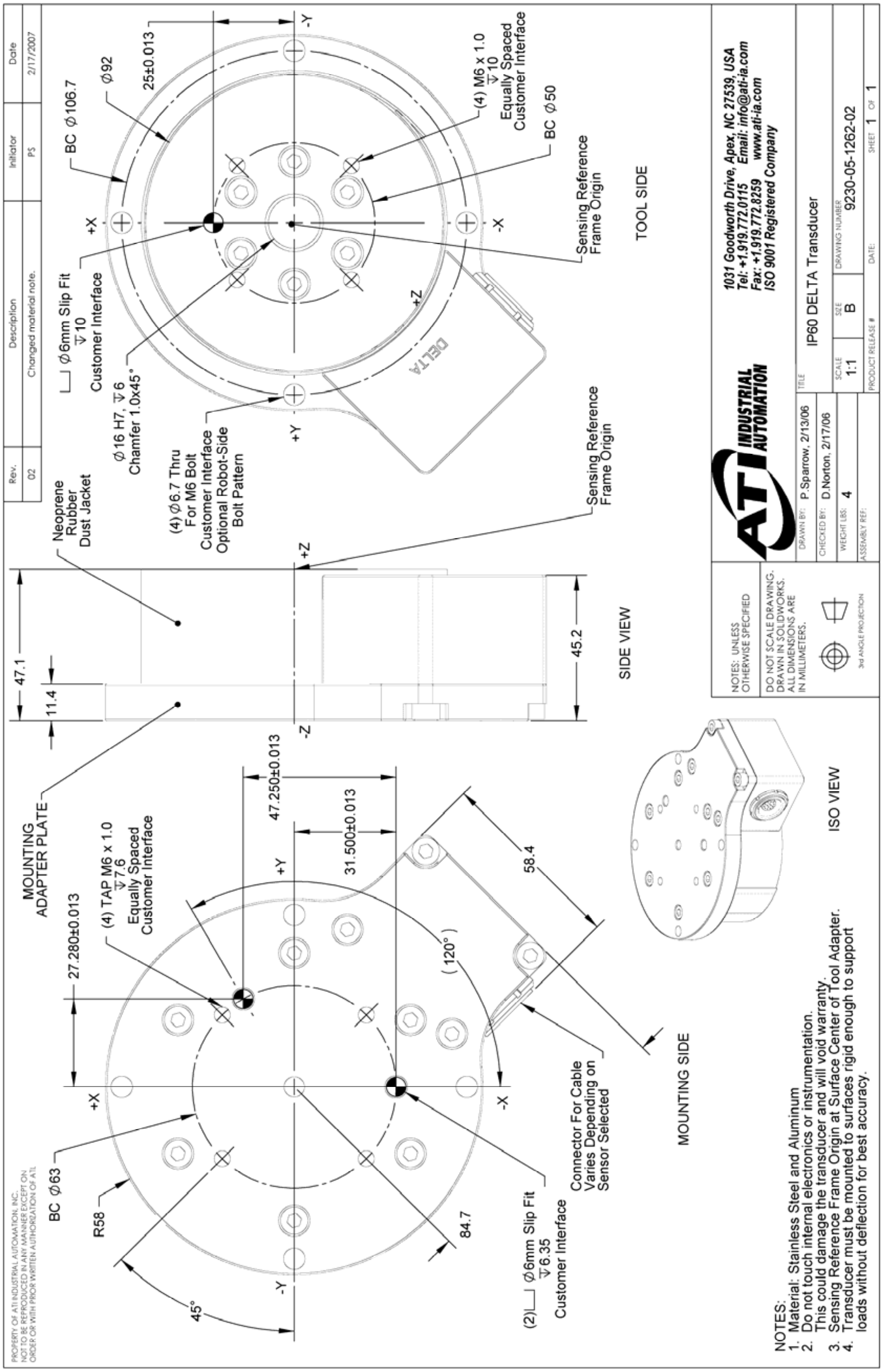
4.8.9 Delta Tool Ring-plug Adapter



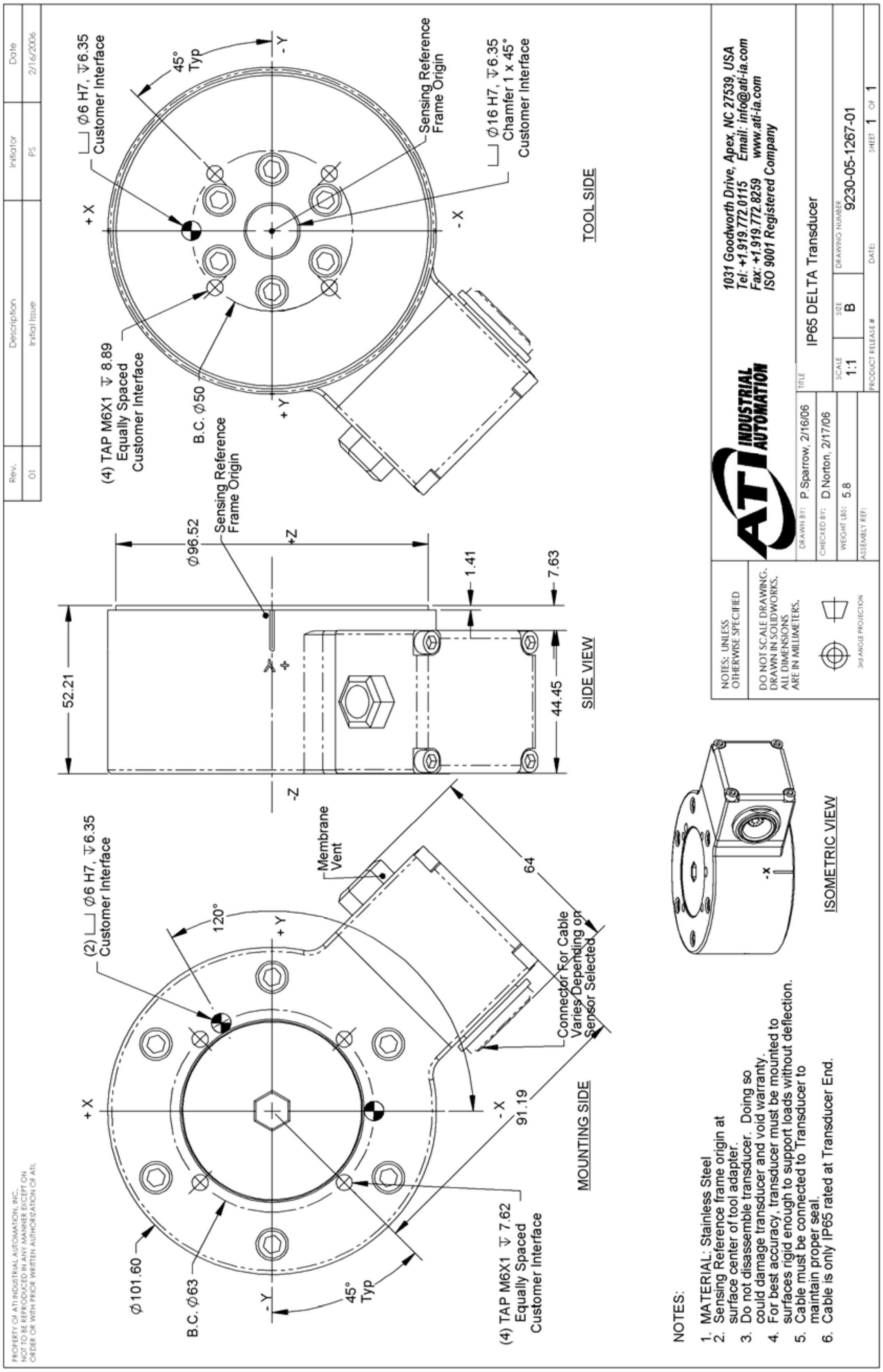
4.8.10 Delta Mounting Ring-plug Adapter



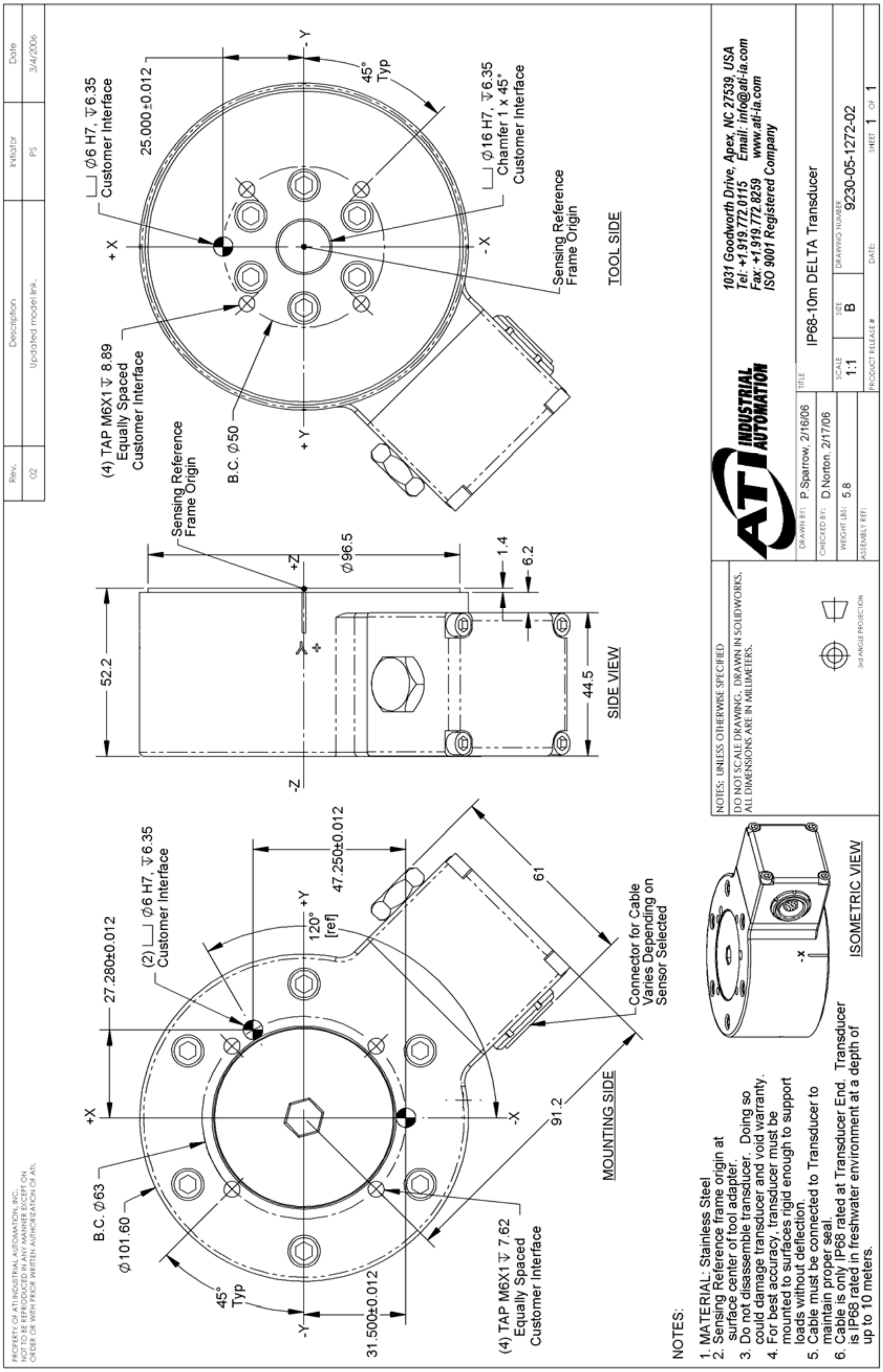
4.8.11 IP60 Delta Transducer



4.8.12 IP65 Rated Delta Transducer



4.8.13 IP68 Delta Transducer



4.9 Theta (Includes IP60/IP65/IP68 Versions)

4.9.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-200-1000**	**US-300-1800**	**US-600-3600**	**SI-1000-120**	**SI-1500-240**	**SI-2500-400**
Rated Sensing Ranges						
Fx, Fy	±200 lbf	±300 lbf	±600 lbf	±1000 N	±1500 N	±2500 N
Fz**	±500 lbf	±875 lbf	±1500 lbf	±2500 N	±3750 N	±6250 N
Tx, Ty, Tz	±1000 lbf-in	±1800 lbf-in	±3600 lbf-in	±120 Nm	±240 Nm	±400 Nm
Resolution (minimum)*						
Fx, Fy	1/32 lbf	5/68 lbf	1/8 lbf	1/4 N	1/2 N	1/2 N
Fz	1/16 lbf	5/34 lbf	1/4 lbf	1/4 N	1/2 N	1 N
Tx, Ty	1/8 lbf-in	5/16 lbf-in	1/2 lbf-in	1/40 Nm	1/20 Nm	1/20 Nm
Tz	1/8 lbf-in	5/16 lbf-in	1/2 lbf-in	1/80 Nm	1/40 Nm	1/20 Nm

*DAQ resolutions are typical for a 16-bit data acquisition system

4.9.2 CTL Calibration Specifications

	US (English)			SI (Metric)		
Calibration	**US-200-1000**	**US-300-1800**	**US-600-3600**	**SI-1000-120**	**SI-1500-240**	**SI-2500-400**
Rated Sensing Ranges						
Fx, Fy	±200 lbf	±300 lbf	±600 lbf	±1000 N	±1500 N	±2500 N
Fz**	±500 lbf	±875 lbf	±1500 lbf	±2500 N	±3750 N	±6250 N
Tx, Ty, Tz	±1000 lbf-in	±1800 lbf-in	±3600 lbf-in	±120 Nm	±240 Nm	±400 Nm
Resolution (minimum)						
Fx, Fy	1/16 lbf	5/34 lbf	1/4 lbf	1/2 N	1 N	1 N
Fz	1/8 lbf	5/17 lbf	1/2 lbf	1/2 N	1 N	2 N
Tx, Ty	1/4 lbf-in	5/8 lbf-in	1 lbf-in	1/20 Nm	1/10 Nm	1/10 Nm
Tz	1/4 lbf-in	5/8 lbf-in	1 lbf-in	1/40 Nm	1/20 Nm	1/10 Nm
Counts Value						
Fx, Fy, Fz	128 / lbf	54.4 / lbf	32 / lbf	32 / N	16 / N	16 / N
Tx, Ty, Tz	64 / lbf-in	12.8 / lbf-in	16 / lbf-in	320 / Nm	160 / Nm	80 / Nm
Analog Output						
Analog Range						
Fx, Fy	±200 lbf	±300 lbf	±600 lbf	±1000 N	±1500 N	±2500 N
Fz**	±500 lbf	±875 lbf	±1500 lbf	±2500 N	±3750 N	±6250 N
Tx, Ty, Tz	±1000 lbf-in	±1800 lbf-in	±3600 lbf-in	±120 Nm	±240 Nm	±400 Nm
±5V Sensitivity						
Fx, Fy	40 lbf/V	60 lbf/V	120 lbf/V	200 N/V	300 N/V	500 N/V
Fz	100 lbf/V	175 lbf/V	300 lbf/V	500 N/V	750 N/V	1250 N/V
Tx, Ty, Tz	200 lbf-in/V	360 lbf-in/V	720 lbf-in/V	24 Nm/V	48 Nm/V	80 Nm/V
±10V Sensitivity						
Fx, Fy	20 lbf/V	30 lbf/V	60 lbf/V	100 N/V	150 N/V	250 N/V
Fz	50 lbf/V	87.5 lbf/V	150 lbf/V	250 N/V	375 N/V	625 N/V
Tx, Ty, Tz	100 lbf-in/V	180 lbf-in/V	360 lbf-in/V	12 Nm/V	24 Nm/V	40 Nm/V
Tool Transform Factor	0.02 in/unit	0.0425 in/unit	0.02 in/unit	1 mm/unit	1 mm/unit	2 mm/unit

**For IP68 version see caution on physical properties page.

4.9.3 Theta Physical Properties (Includes IP60/IP65/IP68 Versions)

	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	390.E+3 lbf/in	68.E+6 N/m
Z-axis force (Kz)	640.E+3 lbf/in	110.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	2.8E+6 in-lbf/rad	320.E+3 Nm/rad
Z-axis torque (Ktz)	4.6E+6 in-lbf/rad	520.E+3 Nm/rad
Resonance (Measured, non-IP Version)		
Fx, Fy, Tz	820 Hz	
Fz, Tx, Ty	680 Hz	
Maximum Single-axis Load		
Fx, Fy	±5,900. lbf	±26,000. N
Fz	±12,000. lbf	±54,000. N
Tx, Ty	±19,000. lbf-in	±2,200. Nm
Tz	±26,000. lbf-in	±2,900. Nm
Weight		
Transducer with standard aluminum MAP plates	9.6 lb	4.4 kg
Transducer with stainless steel plates	14 lb	6.4 kg
IP60	19 lb	8.6 kg
IP65/IP68	19.9 lb	9.1 kg

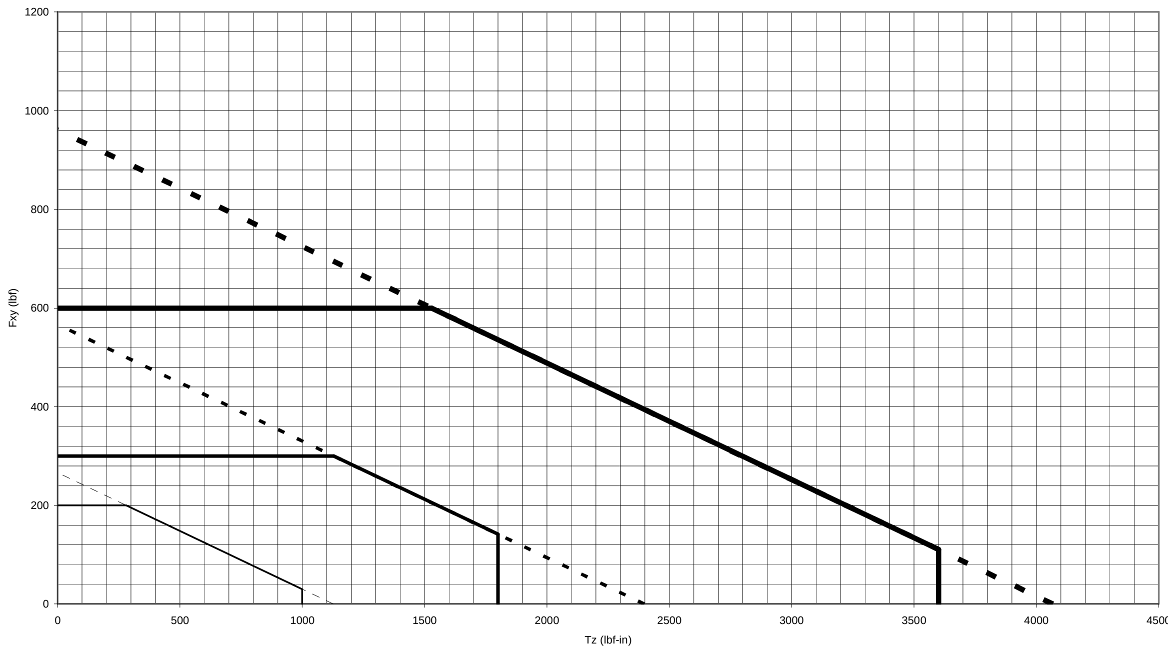
⚠ **CAUTION:**

IP68 Theta Fz as a Function of Submersion Depth:

When submerged, IP68 transducers exhibit a decrease in Fz range related to the submersion depth. This loss is the result of pressure-induced preloading on the transducer. The preload can be masked by biasing the transducer at the depth prior to applying the load to be measured. The following estimates are for room temperature fresh water at seal level.

IP68 Theta	US	Metric
Fz preload at 10m depth	- 429 lb	- 1907 N
Fz preload at other depths	- 13 lb/ft x depthInFeet	- 191 N/m x depthInMeters

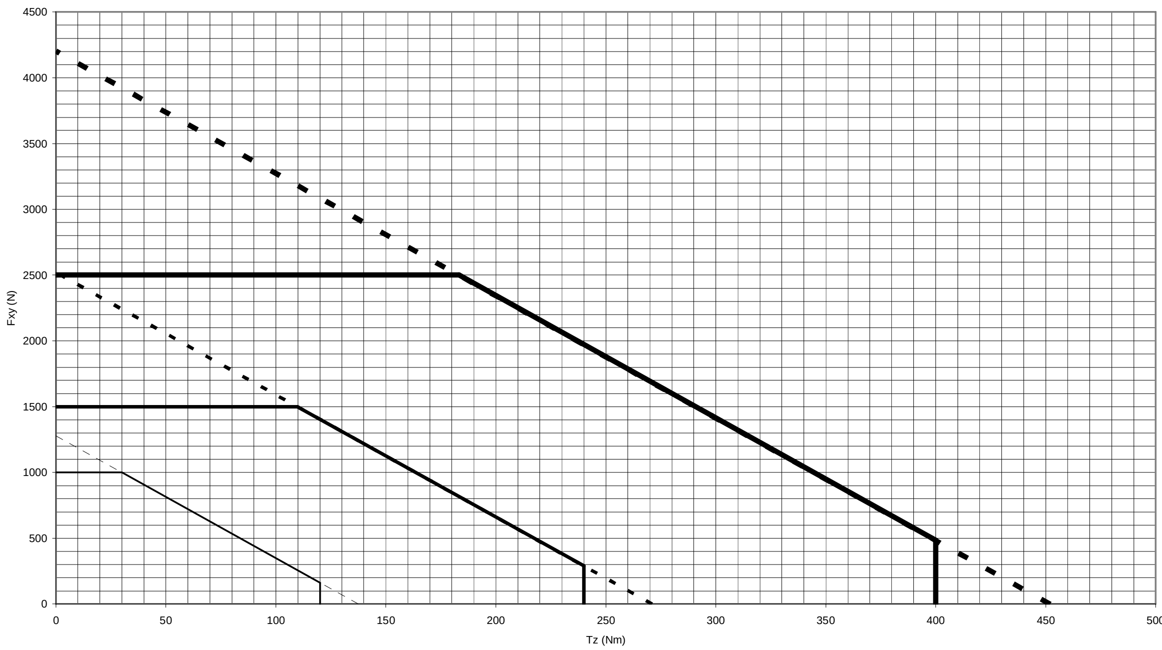
4.9.4 Theta (US Calibration Complex Loading) (Includes IP60/IP65/IP68 Versions)

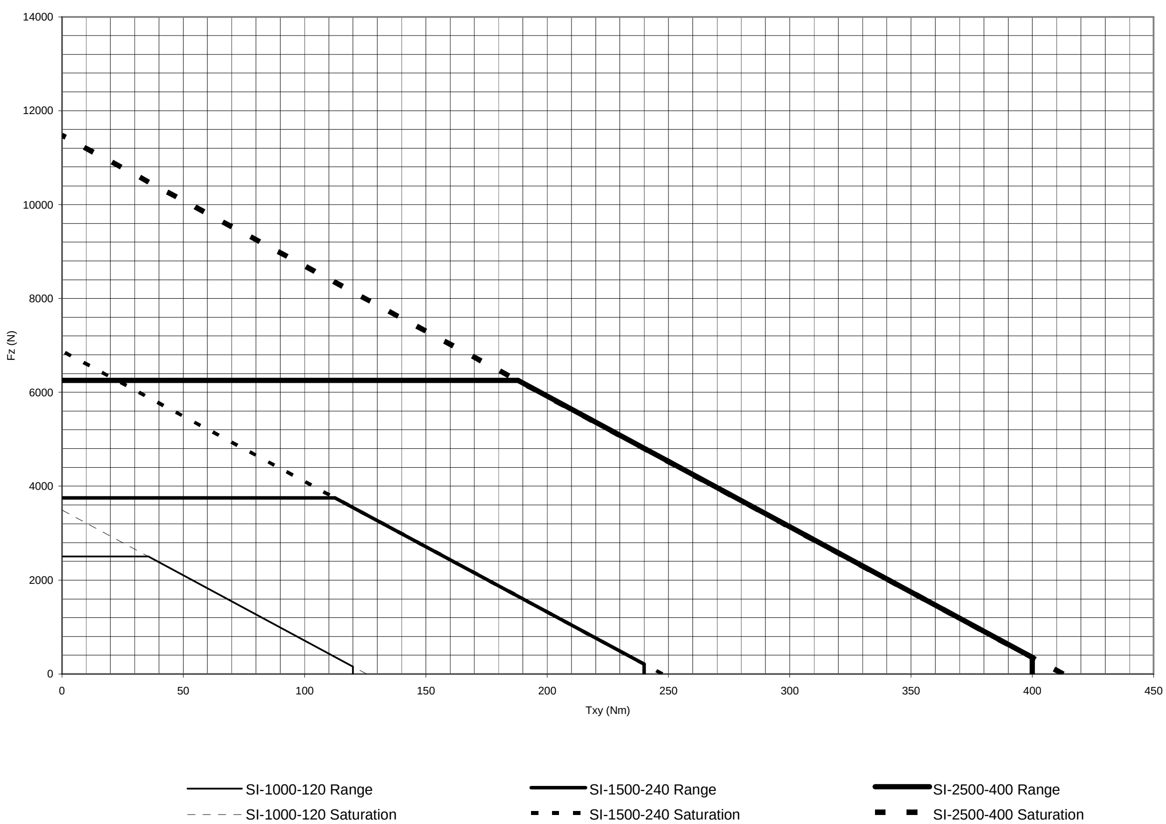


US-200-1000 Range
US-200-1000 Saturation
US-300-1800 Range
US-300-1800 Saturation
US-600-3600 Range
US-600-3600 Saturation

** For IP68 version see caution on physical properties page.

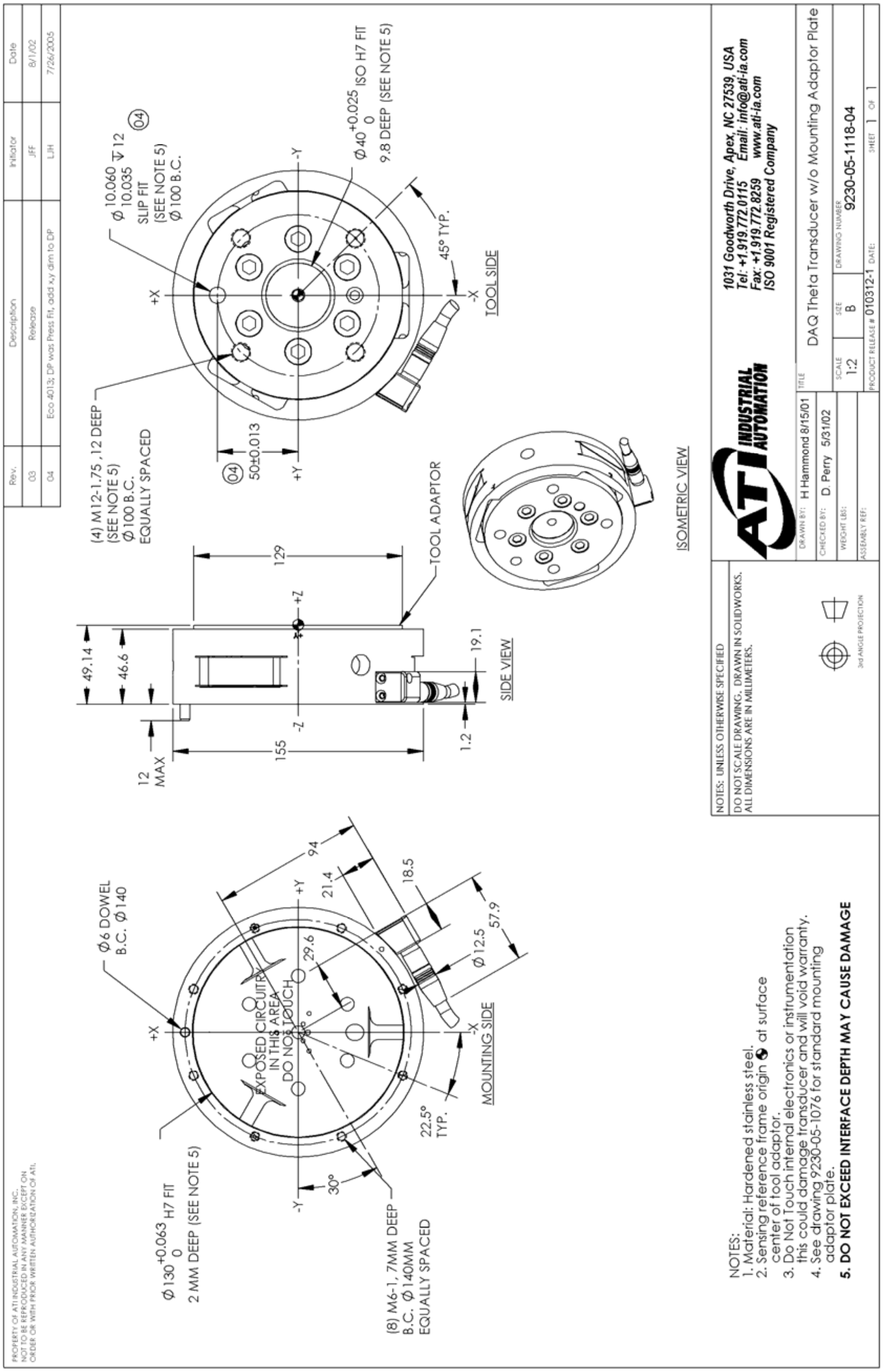
4.9.5 Theta (SI Calibration Complex Loading) (Includes IP60/IP65/IP68 Versions)



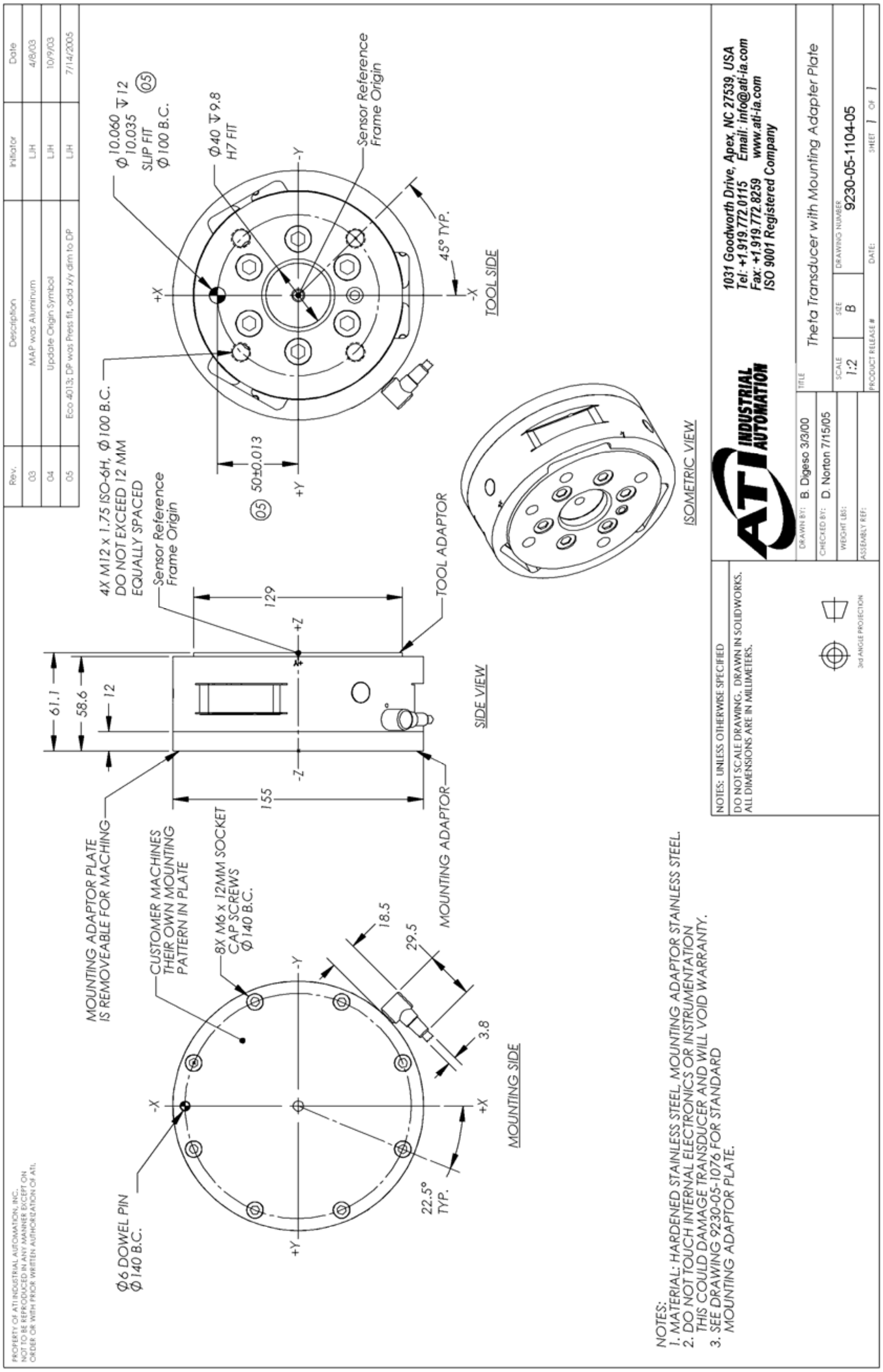


** For IP68 version see caution on physical properties page.

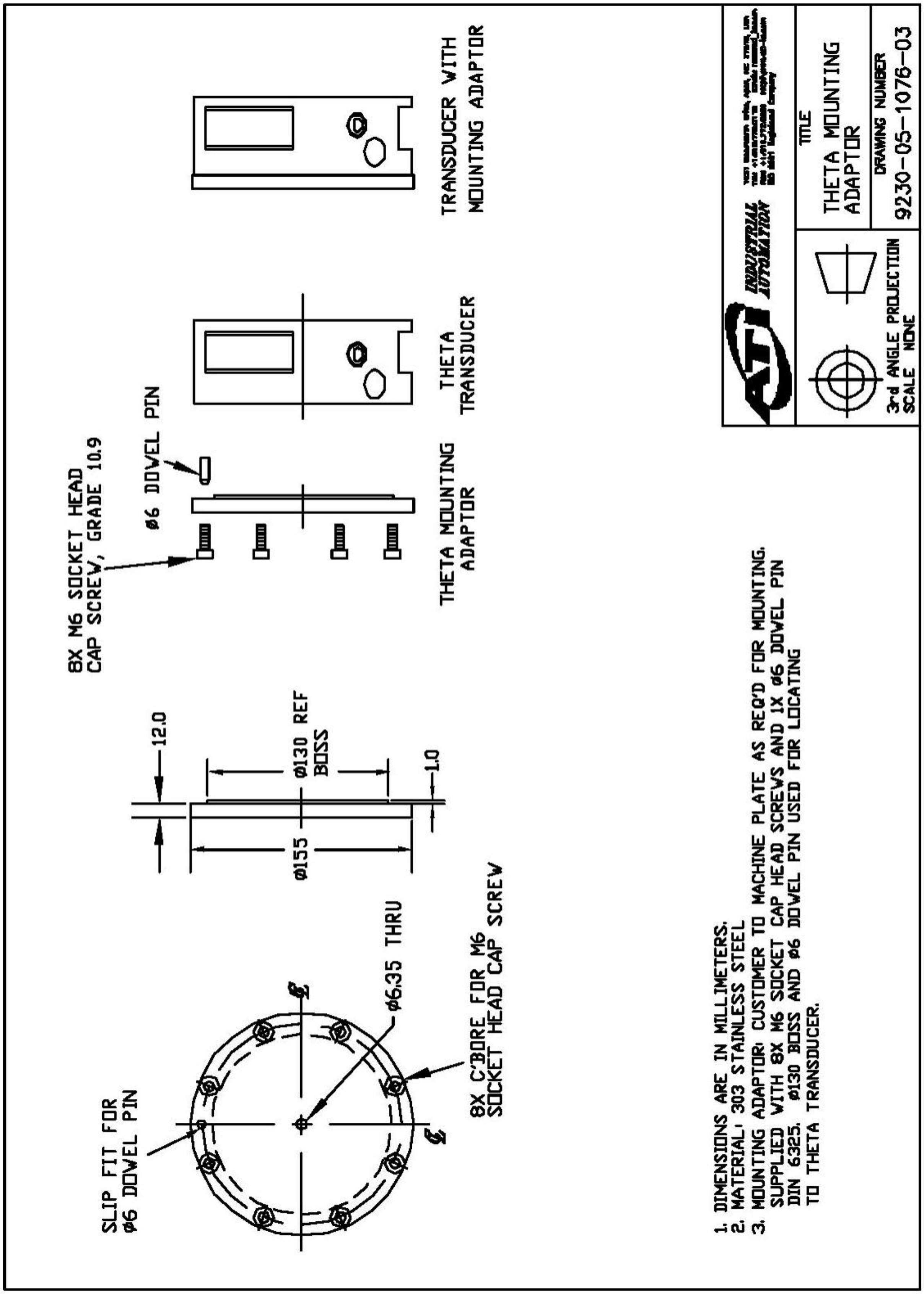
4.9.6 Theta DAQ Transducer with Mounting Adapter Plate



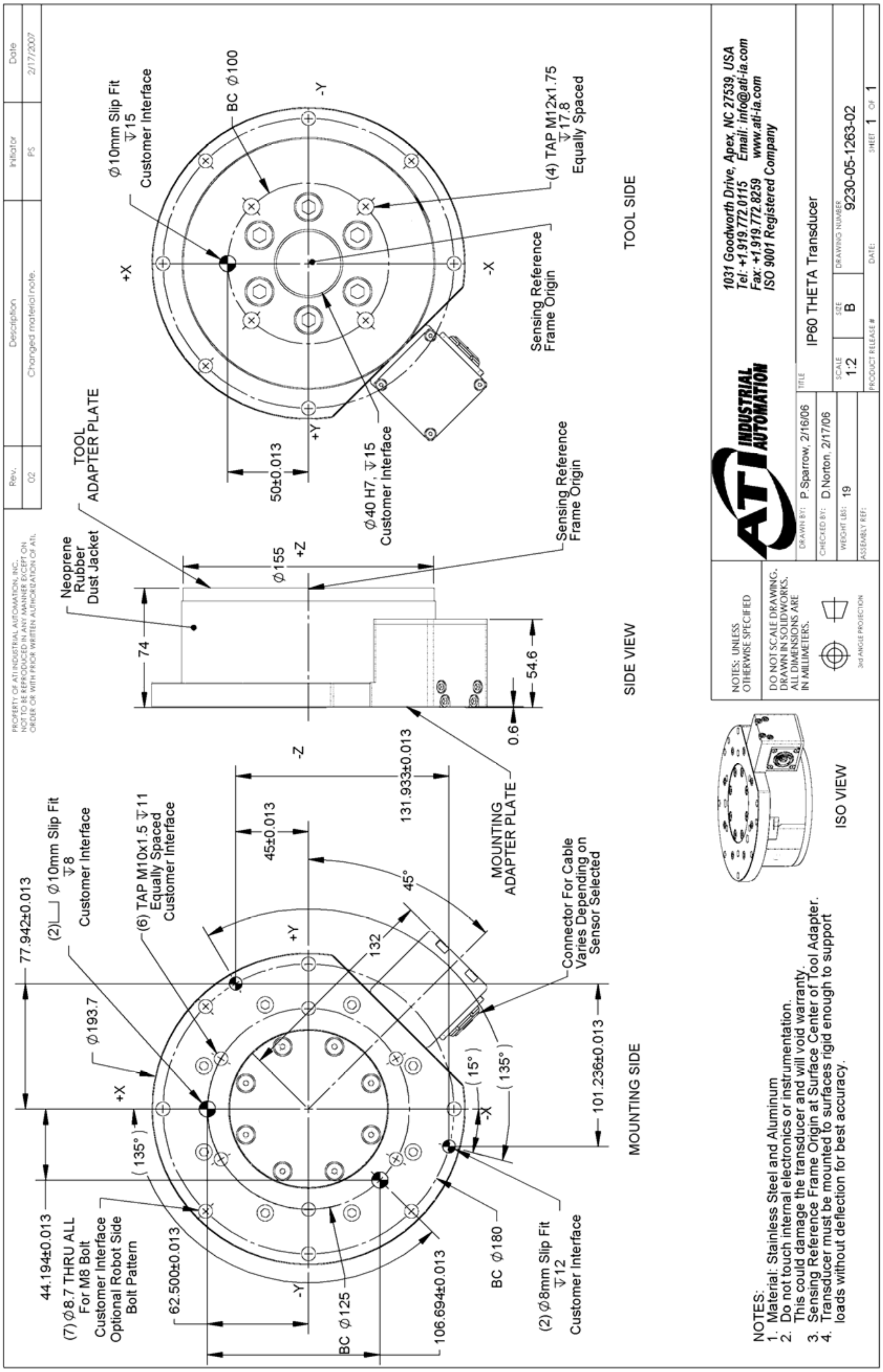
4.9.7 Theta Mux Transducer with Mounting Adapter Plate



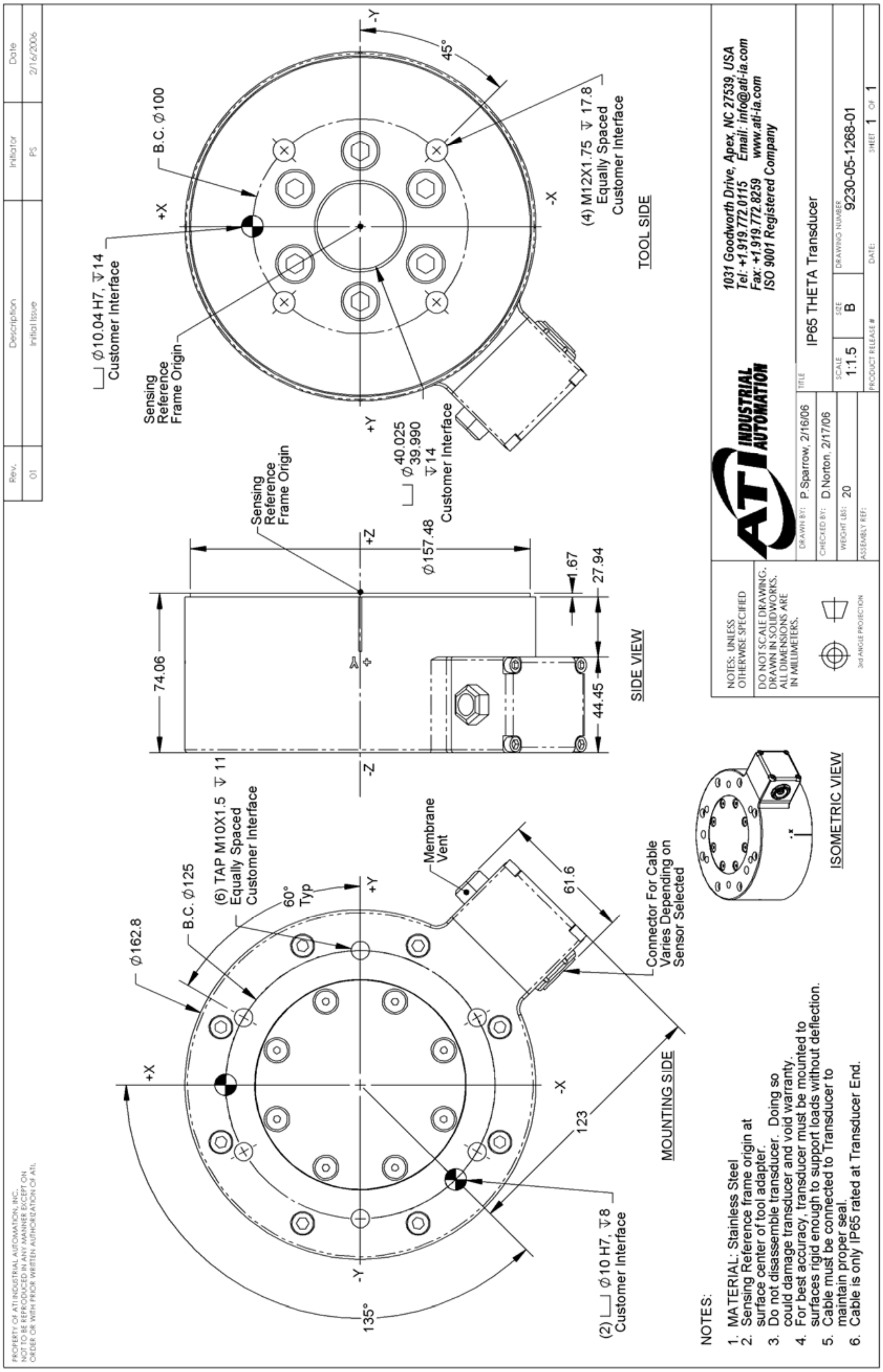
4.9.8 Theta Mounting Adapter Plate



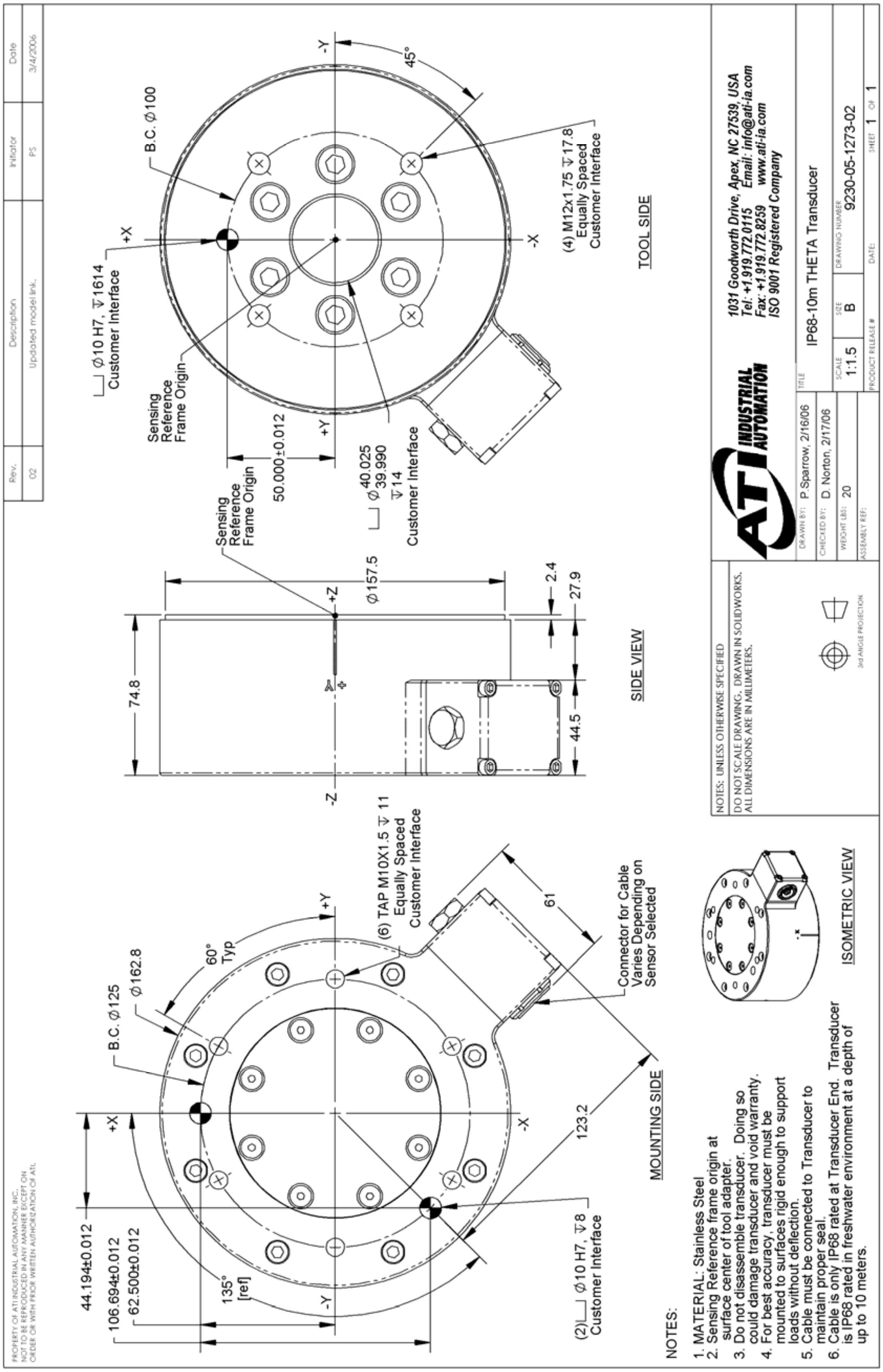
4.9.9 IP60 Theta Transducer



4.9.10 IP65 Theta Transducer



4.9.11 IP68 Theta Transducer



4.10 Omega160 (Includes IP60/IP65/IP68 Versions)

4.10.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-200-1000**	**US-300-1800**	**US-600-3600**	**SI-1000-120**	**SI-1500-240**	**SI-2500-400**
Rated Sensing Ranges						
Fx, Fy	±200 lbf	±300 lbf	±600 lbf	±1000 N	±1500 N	±2500 N
Fz**	±500 lbf	±875 lbf	±1500 lbf	±2500 N	±3750 N	±6250 N
Tx, Ty, Tz	±1000 lbf-in	±1800 lbf-in	±3600 lbf-in	±120 Nm	±240 Nm	±400 Nm
Resolution (minimum)*						
Fx, Fy	1/32 lbf	5/68 lbf	1/8 lbf	1/4 N	1/2 N	1/2 N
Fz	1/16 lbf	5/34 lbf	1/4 lbf	1/4 N	1/2 N	3/4 N
Tx, Ty	1/8 lbf-in	5/16 lbf-in	1/2 lbf-in	1/40 Nm	1/40 Nm	1/20 Nm
Tz	1/8 lbf-in	5/16 lbf-in	1/2 lbf-in	1/80 Nm	1/40 Nm	1/20 Nm

*DAQ resolutions are typical for a 16-bit data acquisition system

4.10.2 CTL Calibration Specifications

	US (English)			SI (Metric)		
Calibration	**US-200-1000**	**US-300-1800**	**US-600-3600**	**SI-1000-120**	**SI-1500-240**	**SI-2500-400**
Rated Sensing Ranges						
Fx, Fy	±200 lbf	±300 lbf	±600 lbf	±1000 N	±1500 N	±2500 N
Fz**	±500 lbf	±875 lbf	±1500 lbf	±2500 N	±3750 N	±6250 N
Tx, Ty, Tz	±1000 lbf-in	±1800 lbf-in	±3600 lbf-in	±120 Nm	±240 Nm	±400 Nm
Resolution (minimum)						
Fx, Fy	1/16 lbf	5/34 lbf	1/4 lbf	1/2 N	1 N	1 N
Fz	1/8 lbf	5/17 lbf	1/2 lbf	1/2 N	1 N	2 N
Tx, Ty	1/4 lbf-in	5/8 lbf-in	1 lbf-in	1/20 Nm	1/10 Nm	1/10 Nm
Tz	1/4 lbf-in	5/8 lbf-in	1 lbf-in	1/40 Nm	1/20 Nm	1/10 Nm
Counts Value						
Fx, Fy, Fz	128 / lbf	54.4 / lbf	32 / lbf	32 / N	16 / N	16 / N
Tx, Ty, Tz	64 / lbf-in	12.8 / lbf-in	16 / lbf-in	320 / Nm	160 / Nm	80 / Nm
Analog Output						
Analog Range						
Fx, Fy	±200 lbf	±300 lbf	±600 lbf	±1000 N	±1500 N	±2500 N
Fz**	±500 lbf	±875 lbf	±1500 lbf	±2500 N	±3750 N	±6250 N
Tx, Ty, Tz	±1000 lbf-in	±1800 lbf-in	±3600 lbf-in	±120 Nm	±240 Nm	±400 Nm
±5V Sensitivity						
Fx, Fy	40 lbf/V	60 lbf/V	120 lbf/V	200 N/V	300 N/V	500 N/V
Fz	100 lbf/V	175 lbf/V	300 lbf/V	500 N/V	750 N/V	1250 N/V
Tx, Ty, Tz	200 lbf-in/V	360 lbf-in/V	720 lbf-in/V	24 Nm/V	48 Nm/V	80 Nm/V
±10V Sensitivity						
Fx, Fy	20 lbf/V	30 lbf/V	60 lbf/V	100 N/V	150 N/V	250 N/V
Fz	50 lbf/V	87.5 lbf/V	150 lbf/V	250 N/V	375 N/V	625 N/V
Tx, Ty, Tz	100 lbf-in/V	180 lbf-in/V	360 lbf-in/V	12 Nm/V	24 Nm/V	40 Nm/V
Tool Transform Factor	0.02 in/unit	0.0425 in/unit	0.02 in/unit	1 mm/unit	1 mm/unit	2 mm/unit

**For IP68 version see caution on physical properties page.

4.10.3 Omega160 Physical Properties (Includes IP60/IP65/IP68 Versions)

	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	390.E+3 lbf/in	68.E+6 N/m
Z-axis force (Kz)	640.E+3 lbf/in	110.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	2.8E+6 in-lbf/rad	320.E+3 Nm/rad
Z-axis torque (Ktz)	4.6E+6 in-lbf/rad	520.E+3 Nm/rad
Resonance (Measured)		
Fx, Fy, Tz	820 Hz	
Fz, Tx, Ty	680 Hz	
Resonance (Measured, IP60 Version)		
Fx, Fy, Tz	1.1 kHz	
Fz, Tx, Ty	1.0 kHz	
Resonance (Measured, IP65/65 Versions)		
Fx, Fy, Tz	1.2 kHz	
Fz, Tx, Ty	0.9 kHz	
Maximum Single-axis Load		
Fx, Fy	±5,900. lbf	±26,000. N
Fz	±12,000. lbf	±54,000. N
Tx, Ty	±19,000. lbf-in	±2,200. Nm
Tz	±26,000. lbf-in	±2,900. Nm
Weight		
Transducer with standard aluminum MAP plates	6.0 lb	2.9 kg
Transducer with stainless steel plates	12 lb	5443 g
IP60	17 lb	7.7 kg
IP65/IP68	16.25 lb	7.4 kg

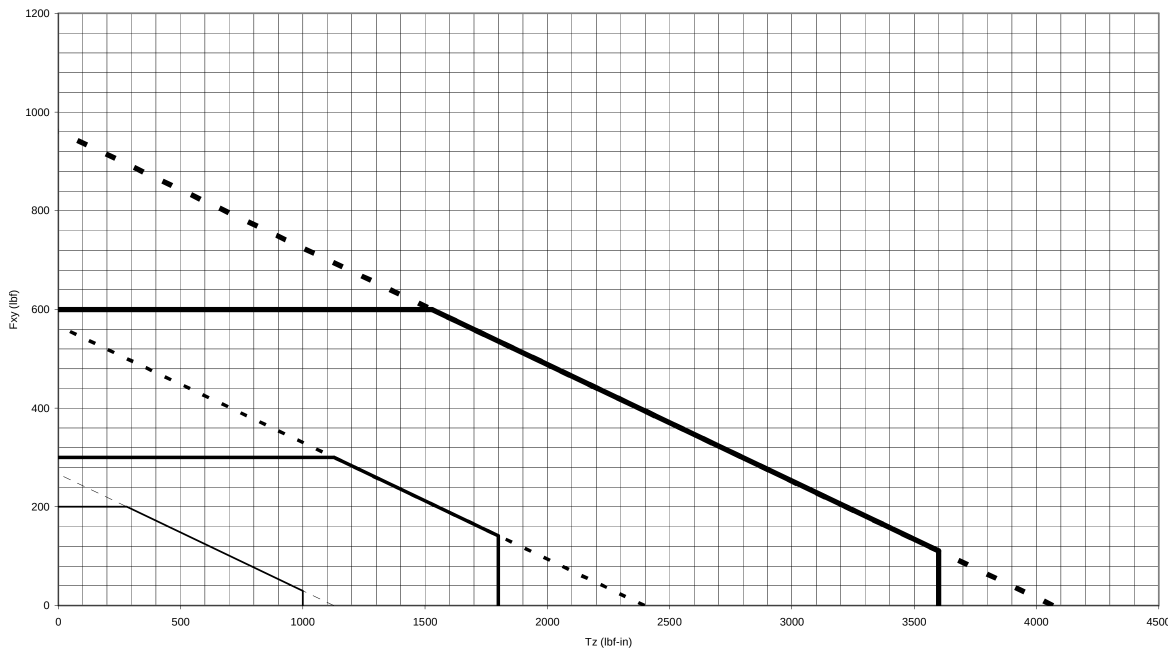
⚠ **CAUTION:**

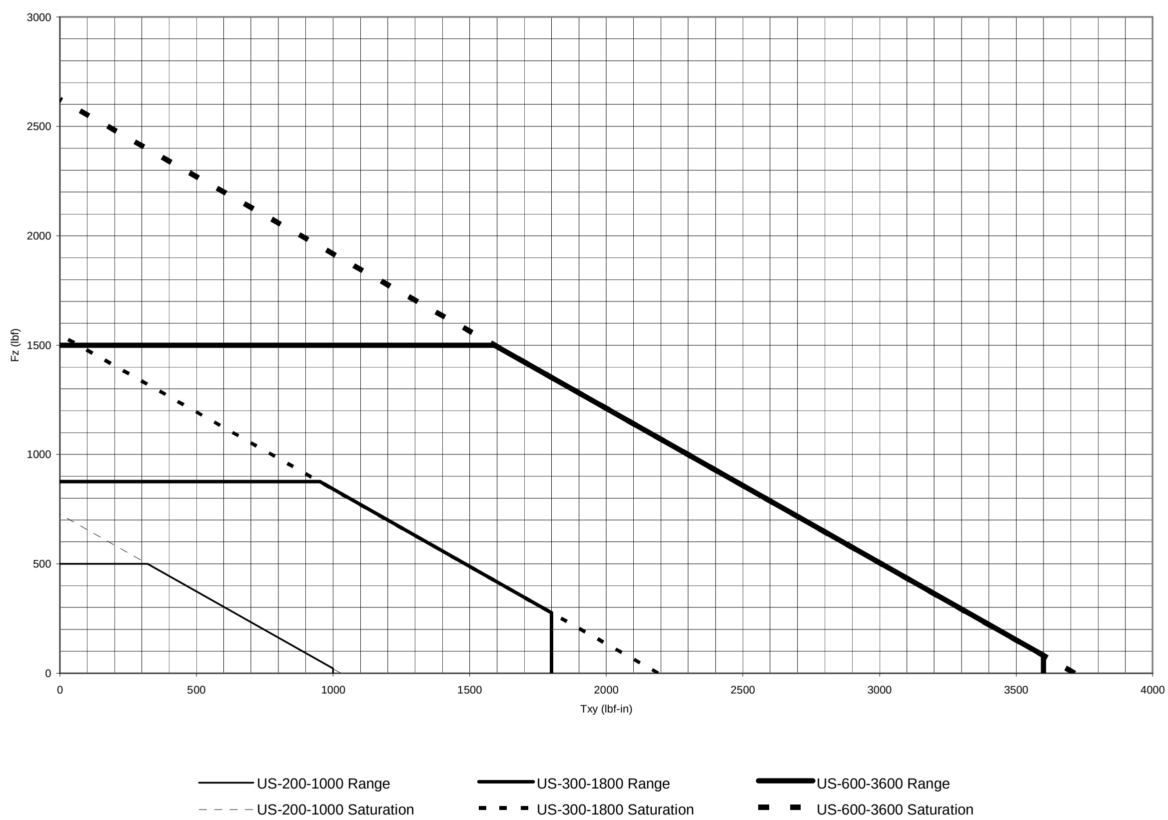
IP68 Omega160 Fz as a Function of Submersion Depth:

When submerged, IP68 transducers exhibit a decrease in Fz range related to the submersion depth. This loss is the result of pressure-induced preloading on the transducer. The preload can be masked by biasing the transducer at the depth prior to applying the load to be measured. The following estimates are for room temperature fresh water at seal level.

IP68 Omega160	US	Metric
Fz preload at 10m depth	- 429 lb	- 1907 N
Fz preload at other depths	- 13 lb/ft x depthInFeet	- 191 N/m x depthInMeters

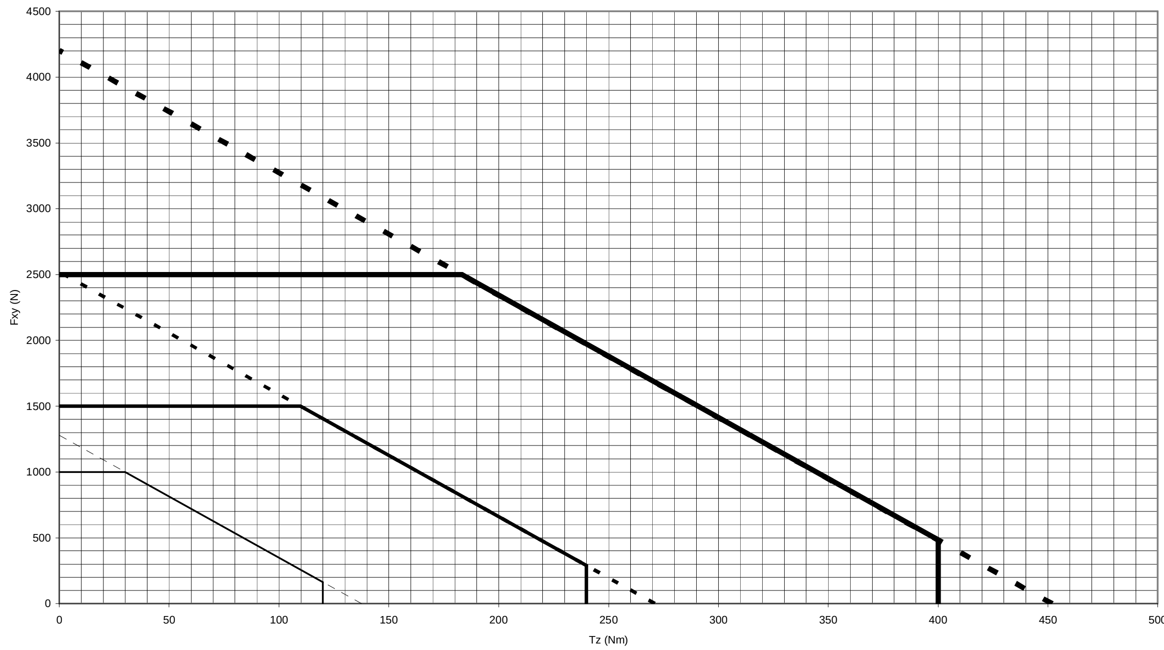
4.10.4 Omega160 (US Calibration Complex Loading) (Includes IP60/IP65/IP68 Versions)

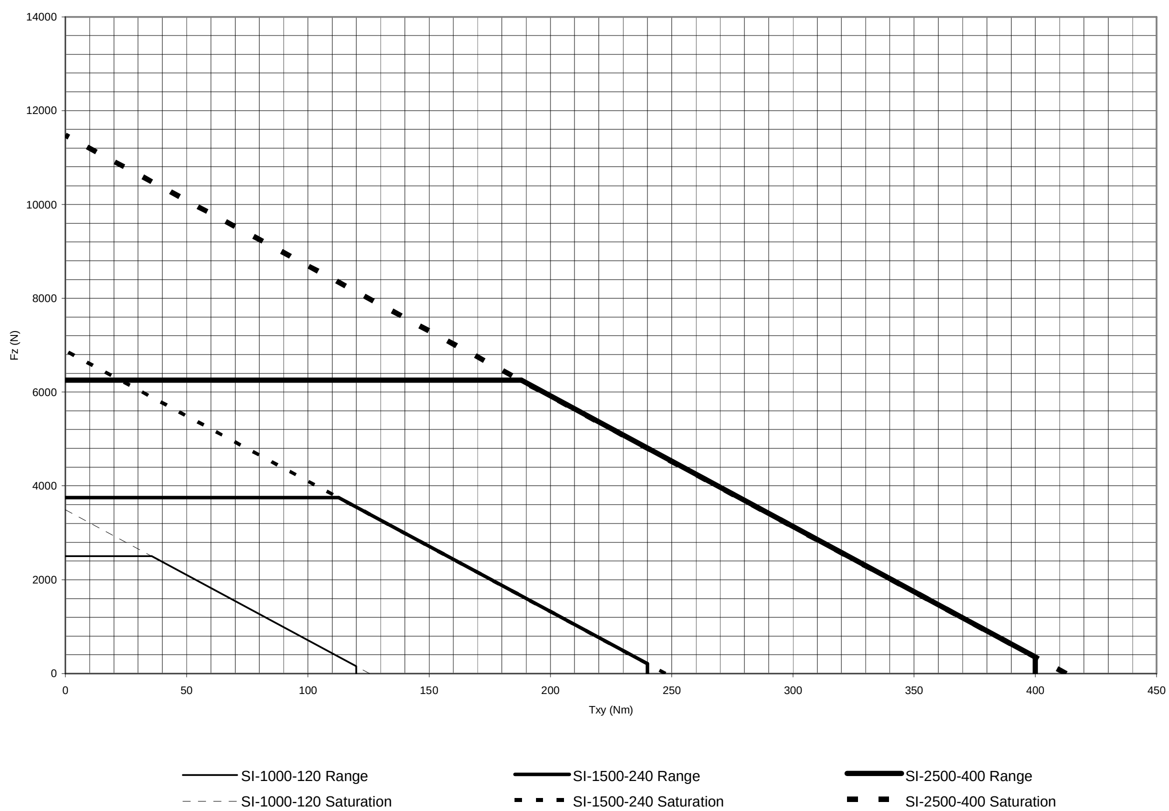




** For IP68 version see caution on physical properties page.

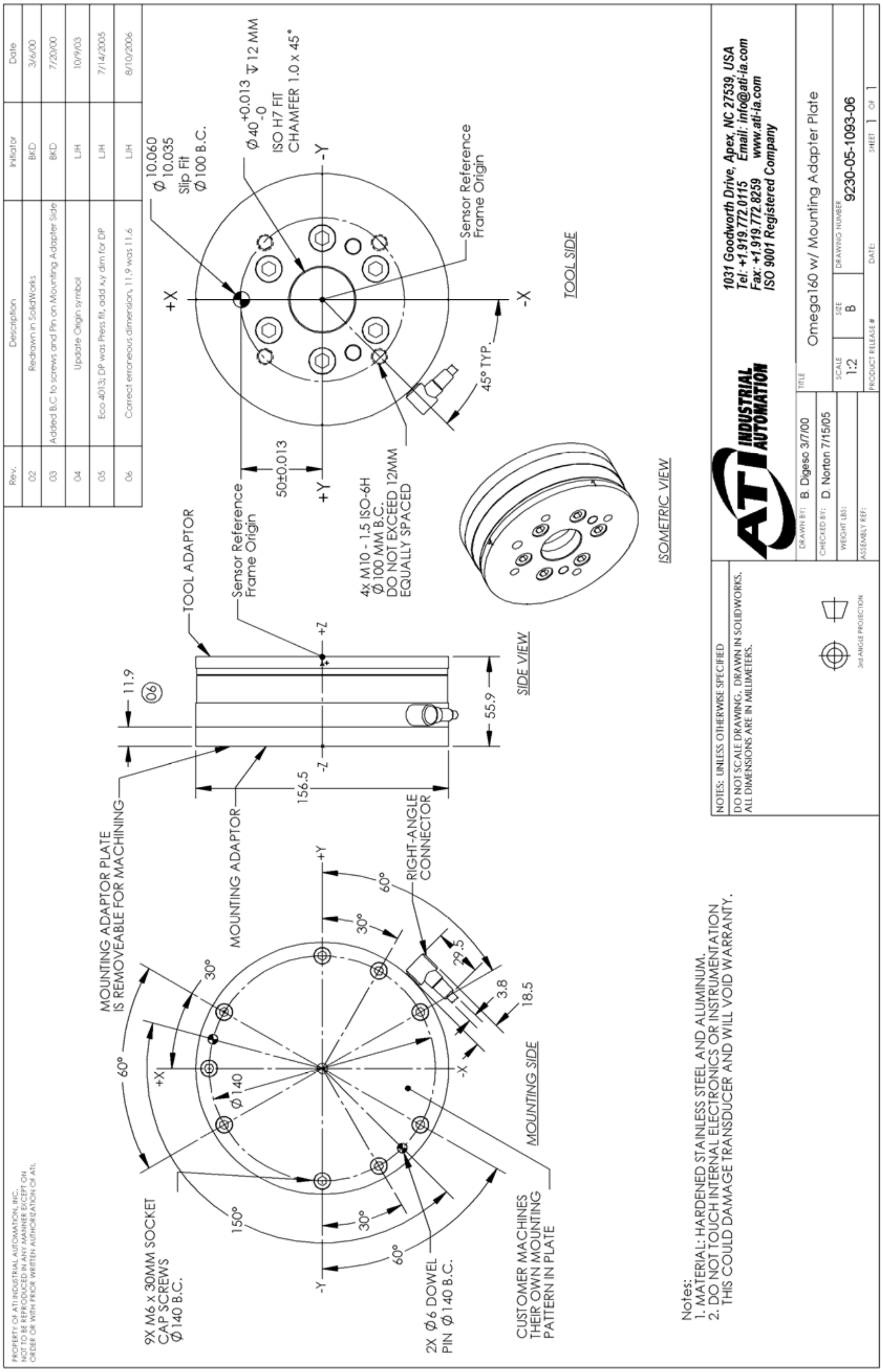
4.10.5 Omega160 (SI Calibration Complex Loading) (Includes IP60/IP65/IP68 Versions)



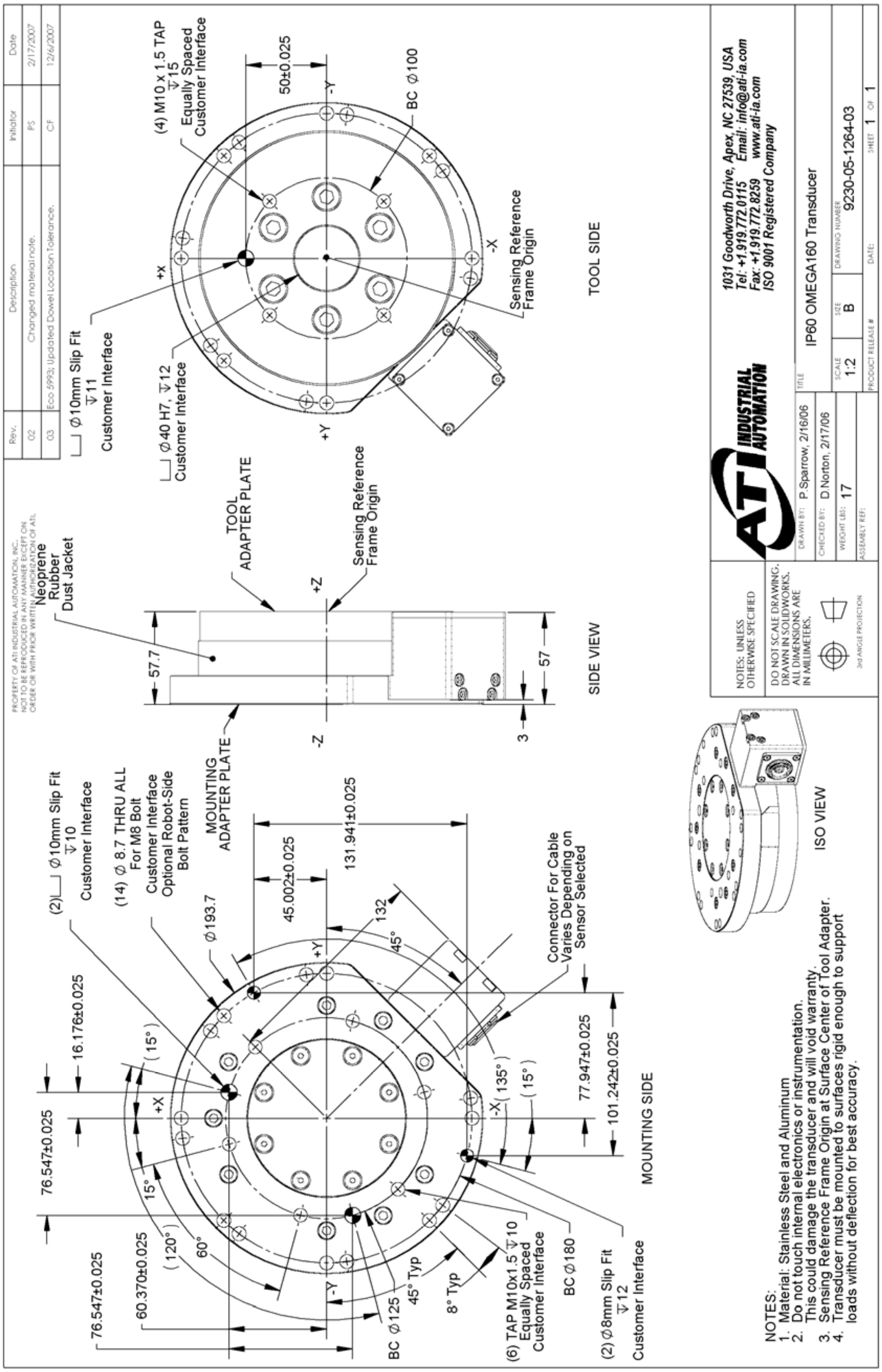


** For IP68 version see caution on physical properties page.

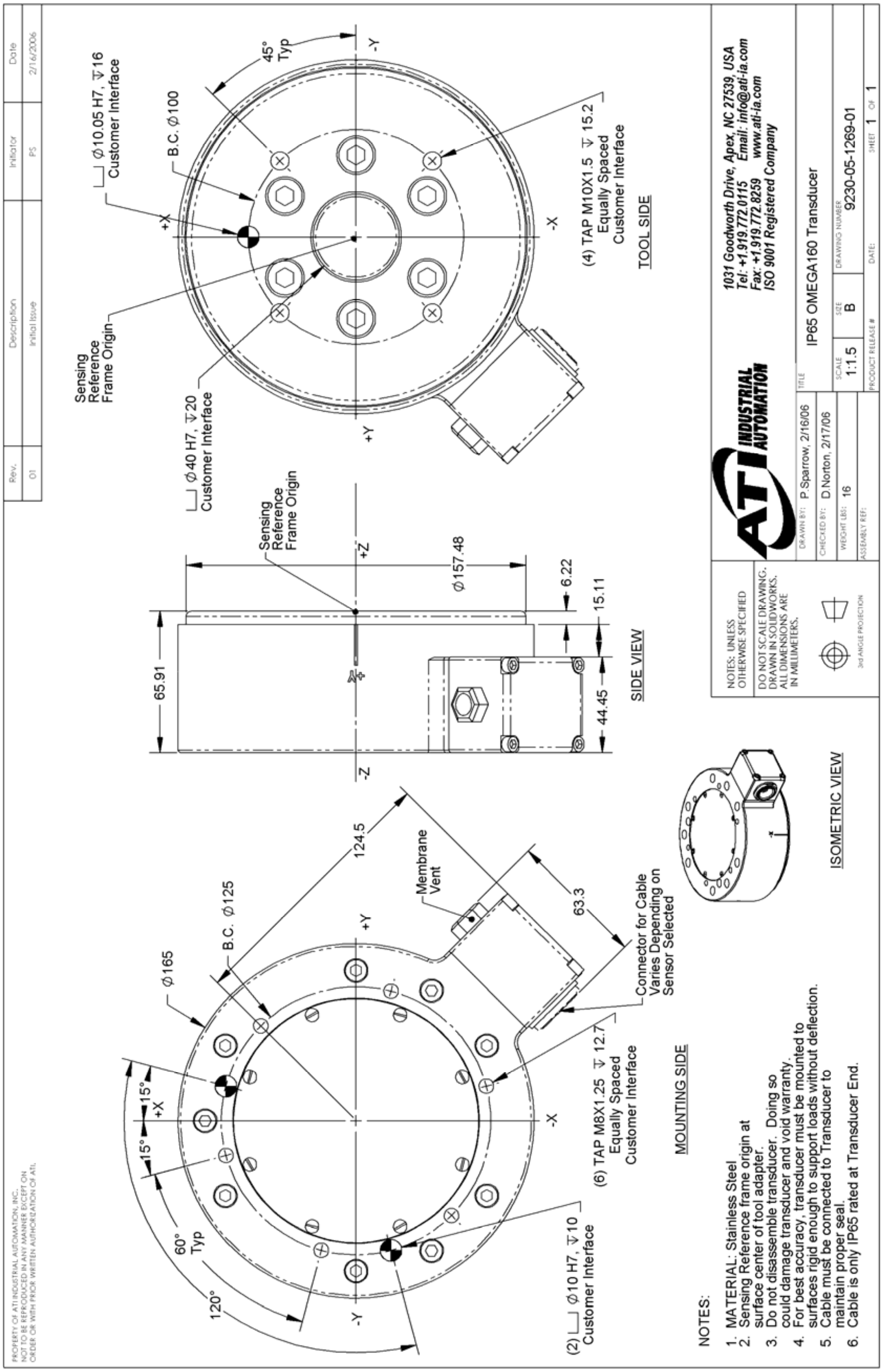
4.10.6 Omega160 Transducer with Mounting Adapter Plate



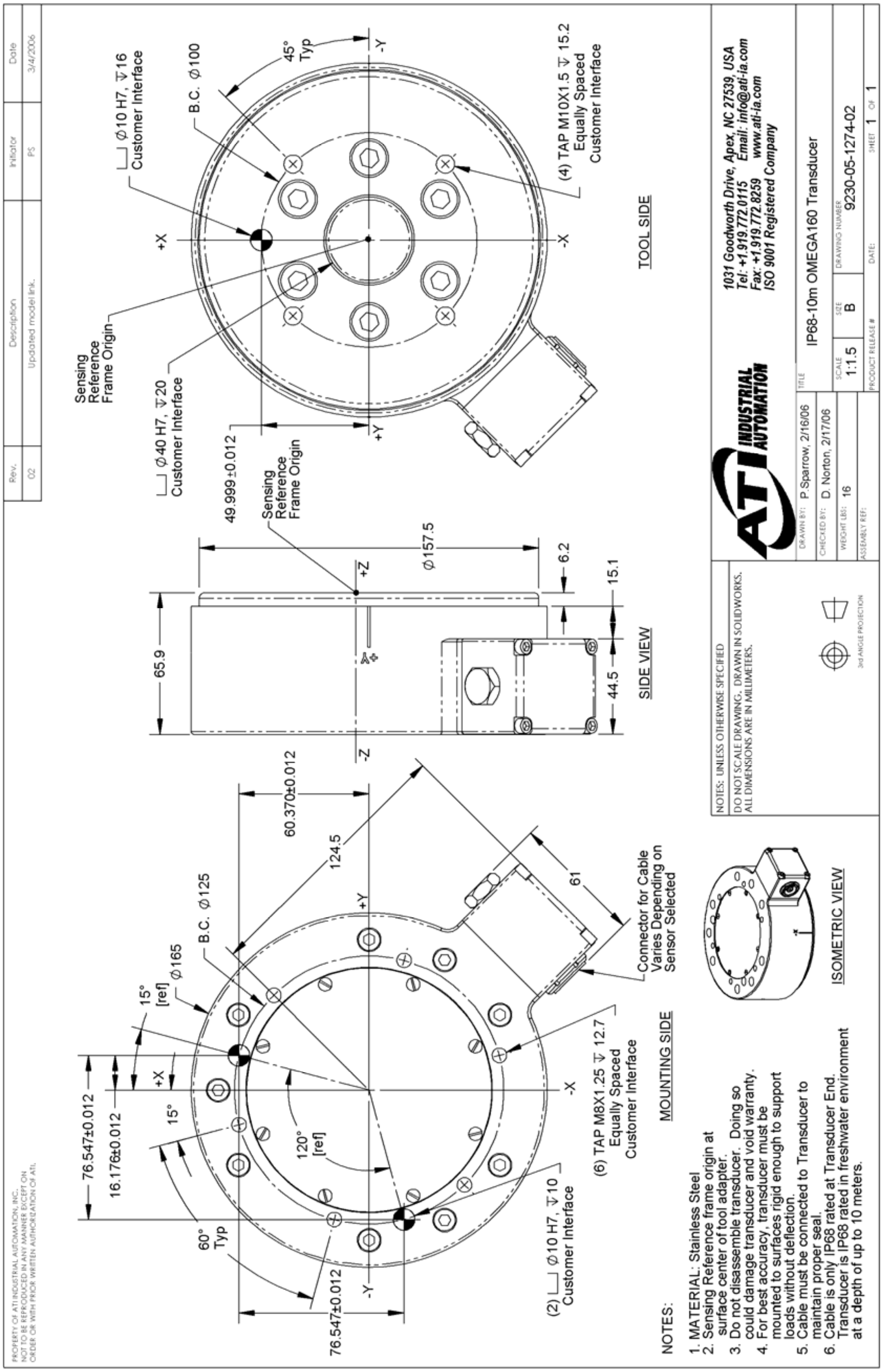
4.10.7 IP60 Omega160 Transducer



4.10.8 IP65 Omega160 Transducer



4.10.9 IP68 Omega160 Transducer



4.11 Omega190 (Includes IP60/IP65/IP68 Versions)

4.11.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-400-3000**	**US-800-6000**	**US-1600-12000**	**SI-1800-350**	**SI-3600-700**	**SI-7200-1400**
Rated Sensing Ranges						
Fx, Fy	±400 lbf	±800 lbf	±1600 lbf	±1800 N	±3600 N	±7200 N
Fz**	±1000 lbf	±2000 lbf	±4000 lbf	±4500 N	±9000 N	±18000 N
Tx, Ty, Tz	±3000 lbf-in	±6000 lbf-in	±12000 lbf-in	±350 Nm	±700 Nm	±1400 Nm
Resolution (minimum)*						
Fx, Fy	5/64 lbf	5/32 lbf	5/16 lbf	3/8 N	3/4 N	1 1/2 N
Fz	5/32 lbf	5/16 lbf	5/8 lbf	3/4 N	1 1/2 N	3 N
Tx, Ty	15/32 lbf-in	15/16 lbf-in	1 7/8 lbf-in	5/96 Nm	5/48 Nm	5/24 Nm
Tz	5/16 lbf-in	5/8 lbf-in	1 1/4 lbf-in	5/144 Nm	5/72 Nm	5/36 Nm

*DAQ resolutions are typical for a 16-bit data acquisition system

4.11.2 CTL Calibration Specifications

	US (English)			SI (Metric)		
Calibration	**US-400-3000**	**US-800-6000**	**US-1600-12000**	**SI-1800-350**	**SI-3600-700**	**SI-7200-1400**
Rated Sensing Ranges						
Fx, Fy	±400 lbf	±800 lbf	±1600 lbf	±1800 N	±3600 N	±7200 N
Fz**	±1000 lbf	±2000 lbf	±4000 lbf	±4500 N	±9000 N	±18000 N
Tx, Ty, Tz	±3000 lbf-in	±6000 lbf-in	±12000 lbf-in	±350 Nm	±700 Nm	±1400 Nm
Resolution (minimum)						
Fx, Fy	5/32 lbf	5/16 lbf	5/8 lbf	3/4 N	1 1/2 N	3 N
Fz	5/16 lbf	5/8 lbf	1 1/4 lbf	1 1/2 N	3 N	6 N
Tx, Ty	15/16 lbf-in	1 7/8 lbf-in	3 3/4 lbf-in	5/48 Nm	5/24 Nm	5/12 Nm
Tz	5/8 lbf-in	1 1/4 lbf-in	2 1/2 lbf-in	5/72 Nm	5/36 Nm	5/18 Nm
Counts Value						
Fx, Fy, Fz	153.6 / lbf	76.8 / lbf	38.4 / lbf	32 / N	16 / N	8 / N
Tx, Ty, Tz	307.2 / lbf-ft	153.6 / lbf-ft	76.8 / lbf-ft	230.4 / Nm	115.2 / Nm	57.6 / Nm
Analog Output						
Analog Range						
Fx, Fy	±400 lbf	±800 lbf	±1600 lbf	±1800 N	±3600 N	±7200 N
Fz**	±1000 lbf	±2000 lbf	±4000 lbf	±4500 N	±9000 N	±18000 N
Tx, Ty, Tz	±3000 lbf-in	±6000 lbf-in	±12000 lbf-in	±350 Nm	±700 Nm	±1400 Nm
±5V Sensitivity						
Fx, Fy	80 lbf/V	160 lbf/V	320 lbf/V	360 N/V	720 N/V	1440 N/V
Fz	200 lbf/V	400 lbf/V	800 lbf/V	900 N/V	1800 N/V	3600 N/V
Tx, Ty, Tz	600 lbf-in/V	1200 lbf-in/V	2400 lbf-in/V	70 Nm/V	140 Nm/V	280 Nm/V
±10V Sensitivity						
Fx, Fy	40 lbf/V	80 lbf/V	160 lbf/V	180 N/V	360 N/V	720 N/V
Fz	100 lbf/V	200 lbf/V	400 lbf/V	450 N/V	900 N/V	1800 N/V
Tx, Ty, Tz	300 lbf-in/V	600 lbf-in/V	1200 lbf-in/V	35 Nm/V	70 Nm/V	140 Nm/V
Tool Transform Factor	0.005 in/unit	0.005 in/unit	0.005 in/unit	1.3889 mm/unit	1.3889 mm/unit	1.3889 mm/unit

**For IP68 version see caution on physical properties page.

4.11.3 Omega190 Physical Properties (Includes IP60/IP65/IP68 Versions)

	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	1.4E+6 lbf/in	240.E+6 N/m
Z-axis force (Kz)	2.1E+6 lbf/in	360.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	14.E+6 in-lbf/rad	1.5E+6 Nm/rad
Z-axis torque (Ktz)	28.E+6 in-lbf/rad	3.2E+6 Nm/rad
Maximum Single-axis Load		
Fx, Fy	±7,900. lbf	±35,000. N
Fz	±24,000. lbf	±100,000. N
Tx, Ty, Tz	±59,000. lbf-in	±6,700. Nm
Tx, Ty, Tz	±69,000. lbf-in	±7,800. Nm
Weight		
Transducer with standard aluminum MAP plates	14 lb	6.4 kg
Transducer with stainless steel plates	19 lb	8.6 kg
IP60	31 lb	14.1 kg
IP65/IP68	29 lb	13.3 kg

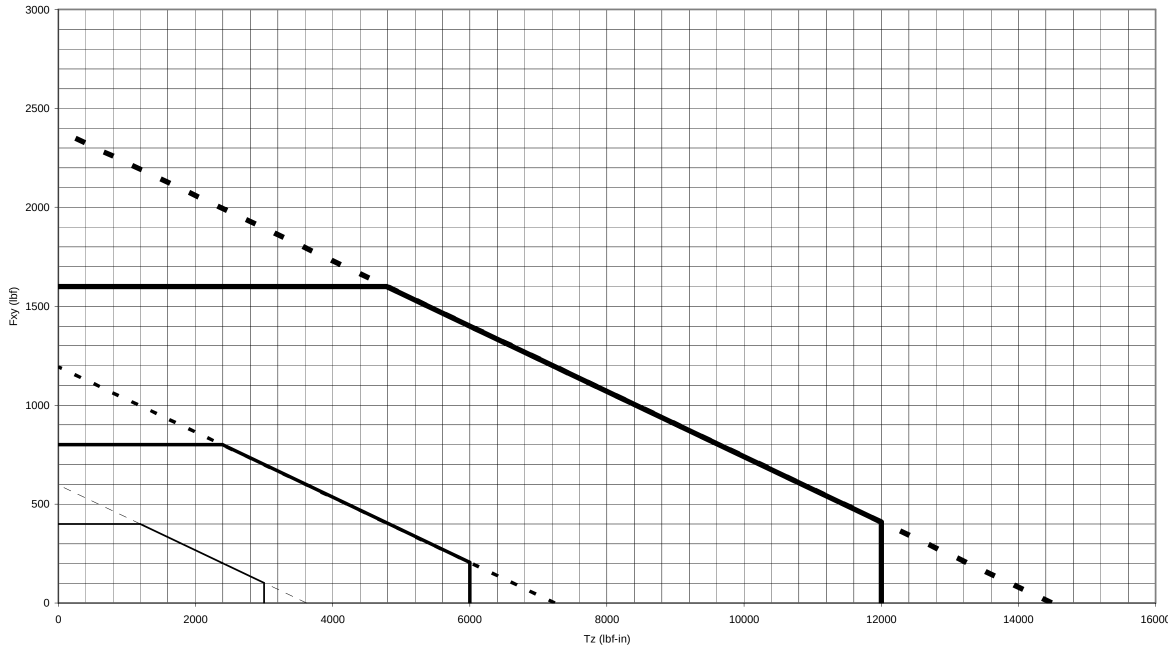
⚠ **CAUTION:**

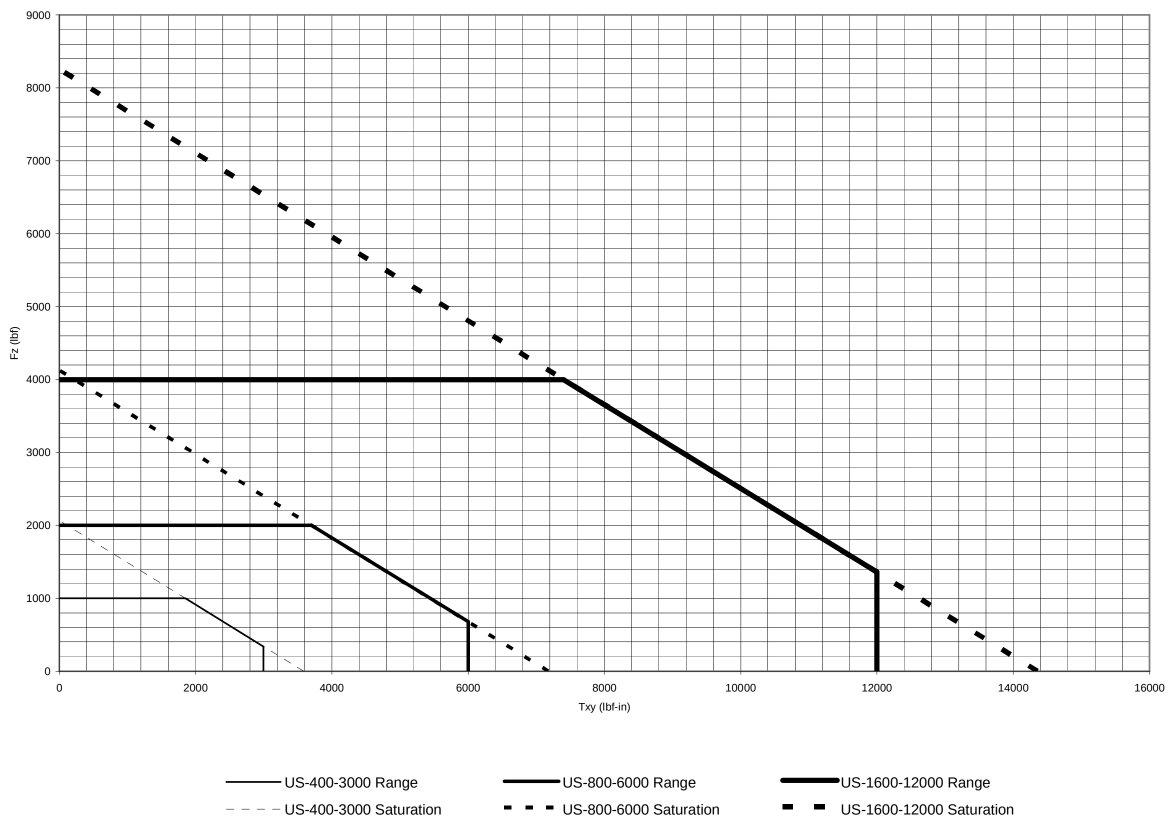
IP68 Omega190 Fz as a Function of Submersion Depth:

When submerged, IP68 transducers exhibit a decrease in Fz range related to the submersion depth. This loss is the result of pressure-induced preloading on the transducer. The preload can be masked by biasing the transducer at the depth prior to applying the load to be measured. The following estimates are for room temperature fresh water at seal level.

IP68 Omega190	**US**	**Metric**
Fz preload at 10m depth	- 661 lb	- 2941 N
Fz preload at other depths	- 20 lb/ft x depthInFeet	- 294 N/m x depthInMeters

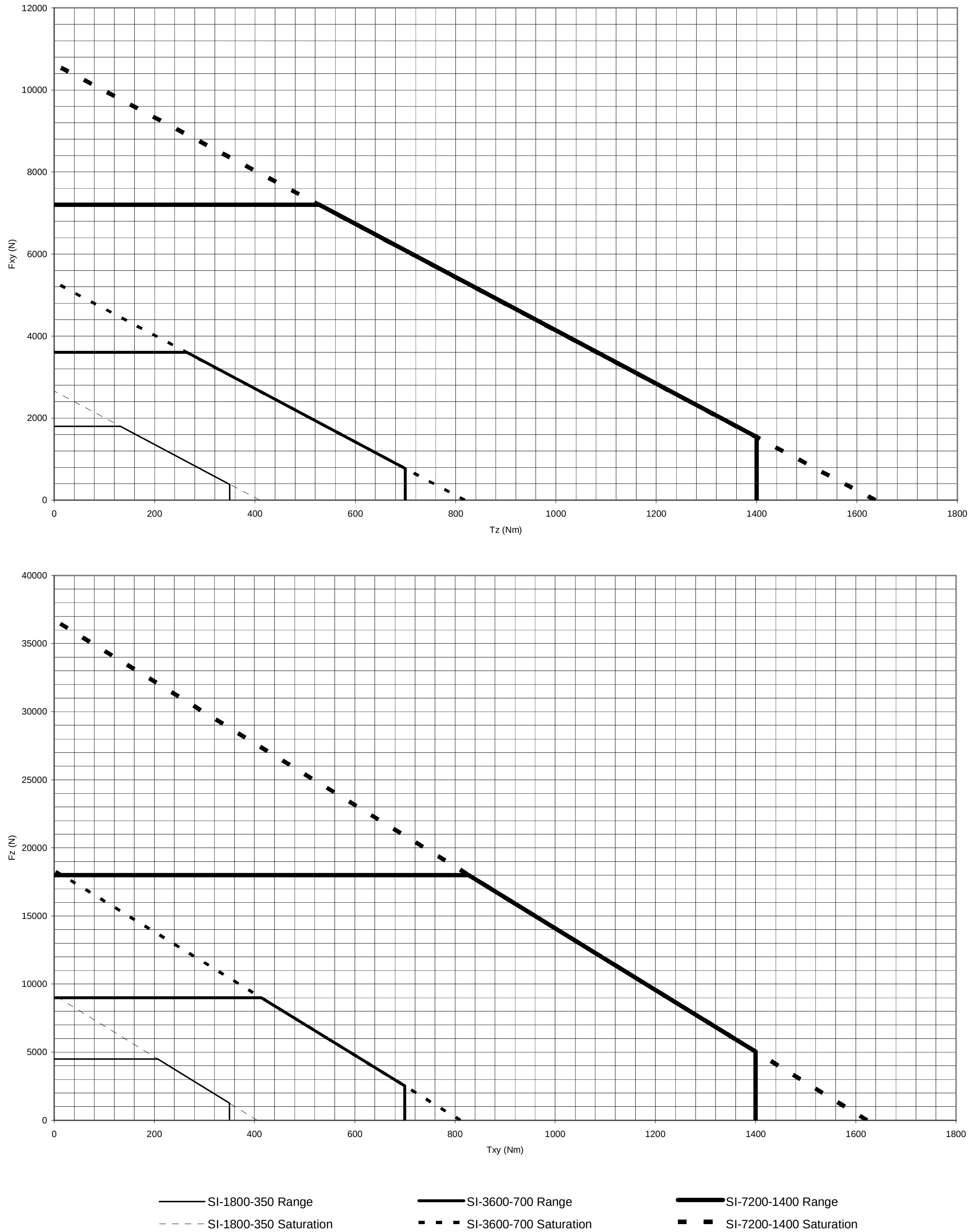
4.11.4 Omega190 (US Calibration Complex Loading) (Includes IP60/IP65/IP68 Versions)





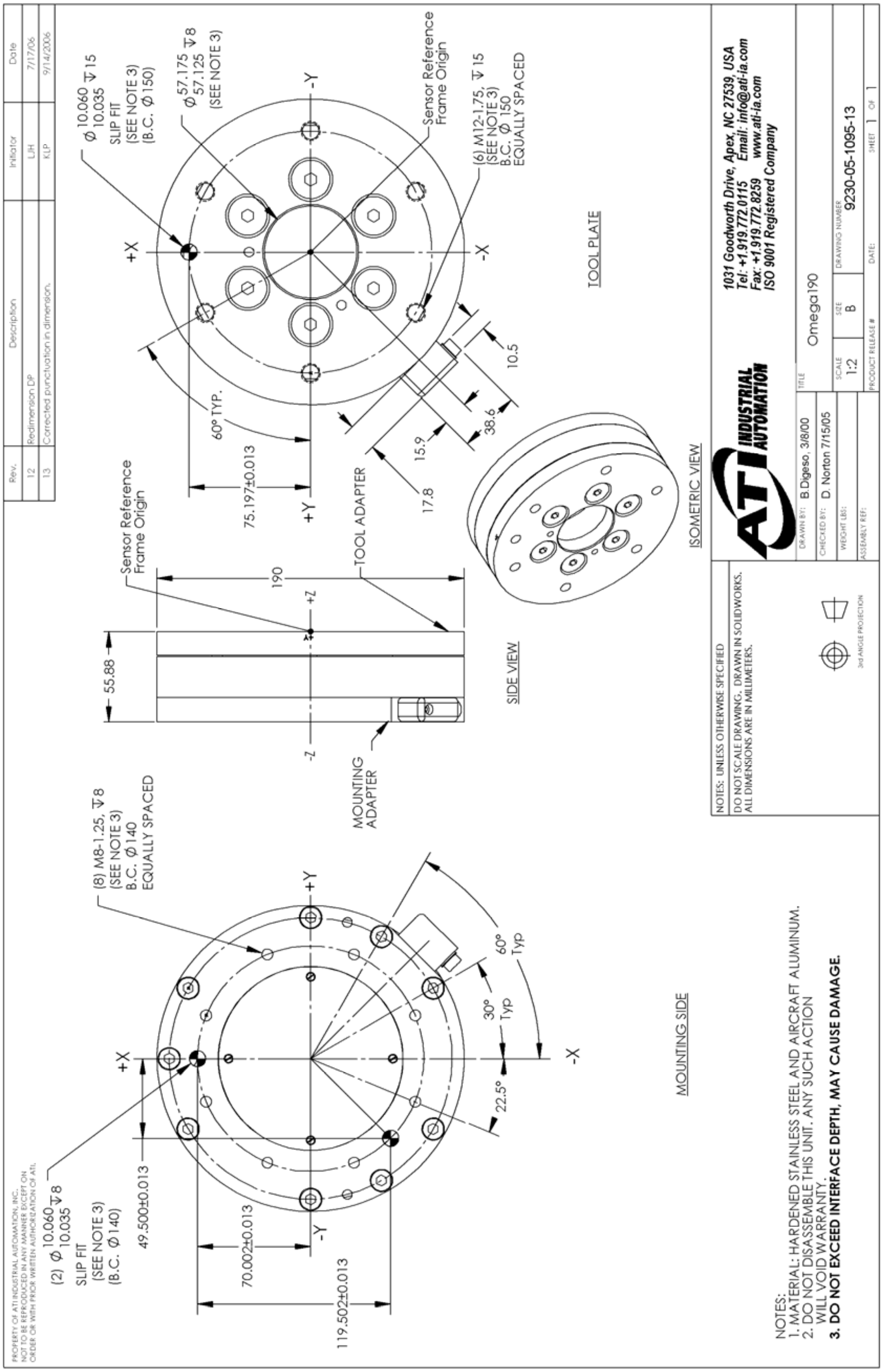
** For IP68 version see caution on physical properties page.

4.11.5 Omega190 (US Calibration Complex Loading) (Includes IP60/IP65/IP68 Versions)

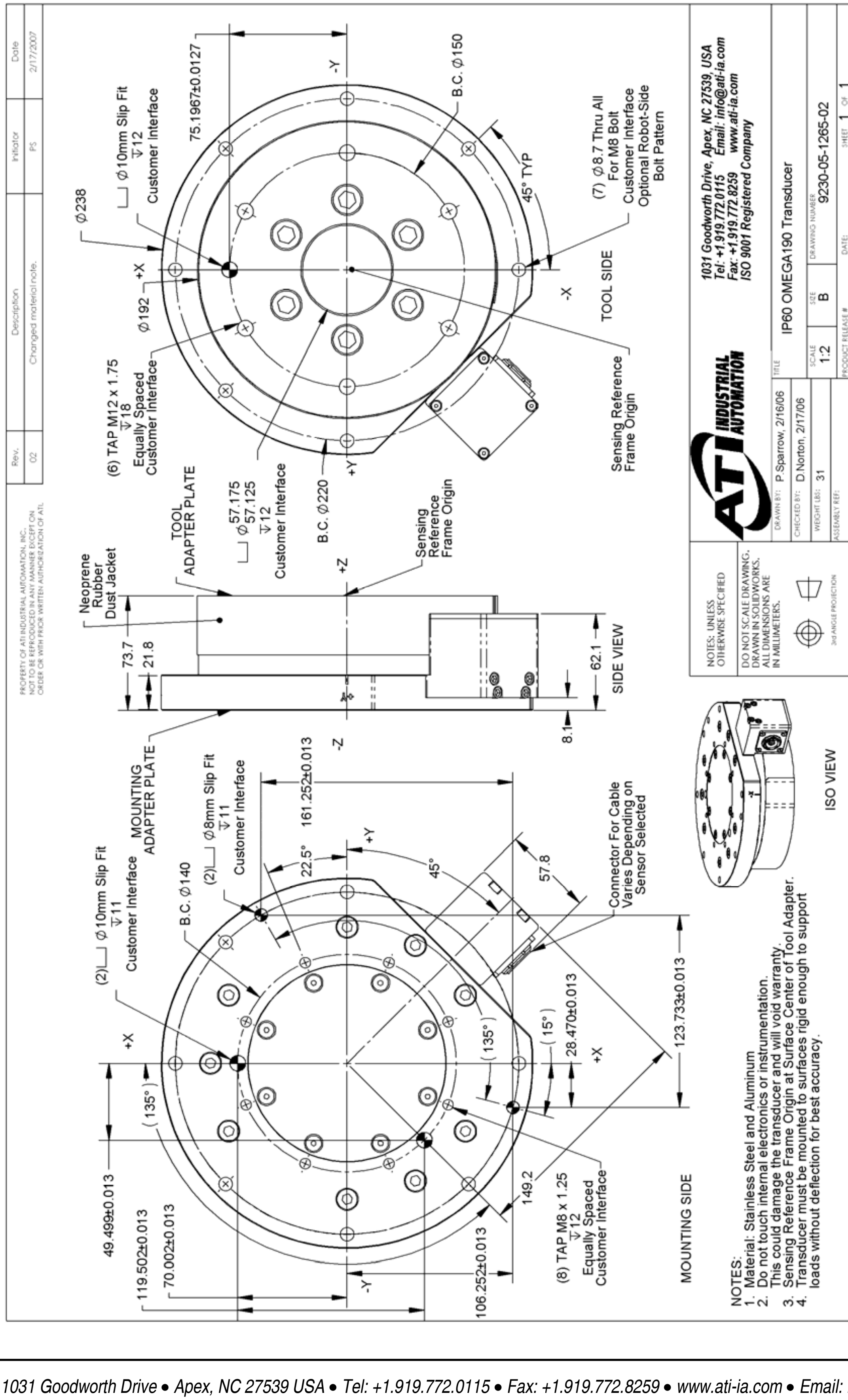


** For IP68 version see caution on physical properties page.

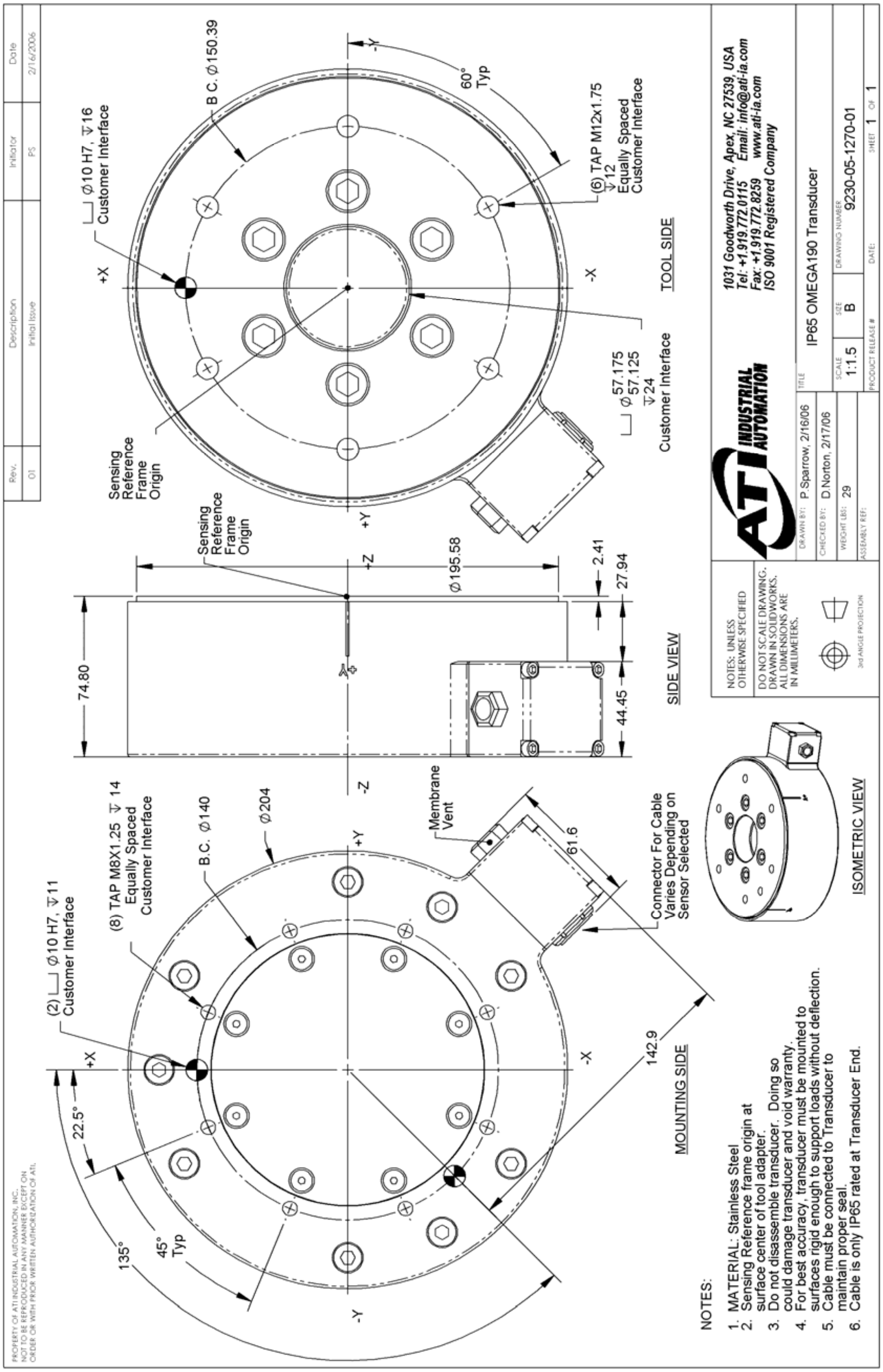
4.11.6 Omega190 Transducer



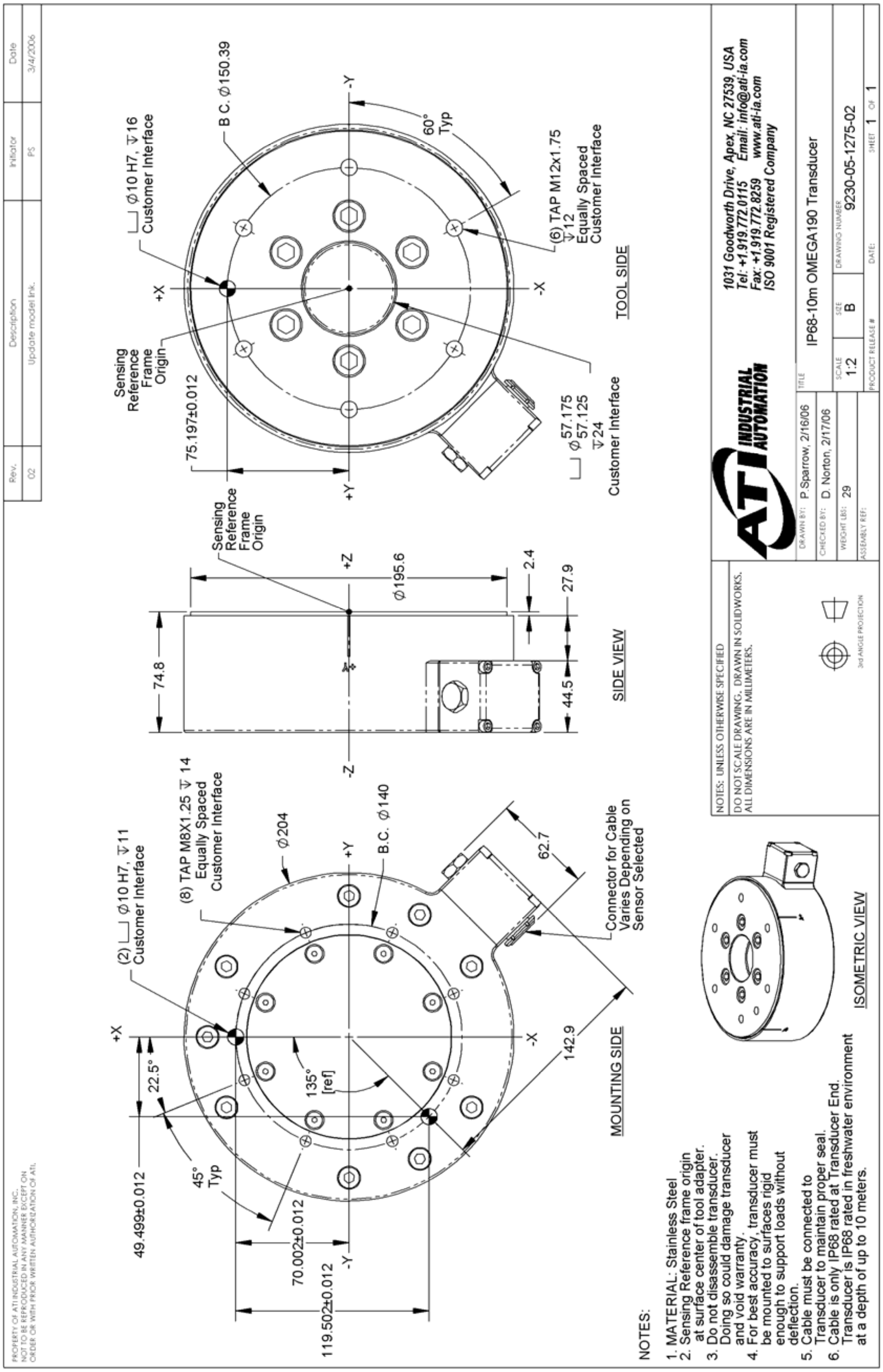
4.11.7 IP60 Omega190 Transducer



4.11.8 IP65 Omega190 Transducer



4.11.9 IP68 Omega190 Transducer



4.12 Omega250 (Includes IP60/IP65/IP68 Versions)

4.12.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-900-4500**	**US-1800-9000**	**US-3600-18000**	**SI-4000-500**	**SI-8000-1000**	**SI-16000-2000**
Rated Sensing Ranges						
Fx, Fy	±900 lbf	±1800 lbf	±3600 lbf	±4000 N	±8000 N	±16000 N
Fz**	±1800 lbf	±3600 lbf	±7200 lbf	±8000 N	±16000 N	±32000 N
Tx, Ty, Tz	±4500 lbf-in	±9000 lbf-in	±18000 lbf-in	±500 Nm	±1000 Nm	±2000 Nm
Resolution (minimum)*						
Fx, Fy	1/2 lbf	1 lbf	2 lbf	1 N	2 N	5 N
Fz	1/2 lbf	1 lbf	2 lbf	2 N	4 N	10 N
Tx, Ty	1 lbf-in	2 lbf-in	5 lbf-in	1/8 Nm	1/4 Nm	1/2 Nm
Tz	1 lbf-in	2 lbf-in	5 lbf-in	1/8 Nm	1/4 Nm	1/2 Nm

*DAQ resolutions are typical for a 16-bit data acquisition system

4.12.2 CTL Calibration Specifications

	US (English)			SI (Metric)		
Calibration	**US-900-4500**	**US-1800-9000**	**US-3600-18000**	**SI-4000-500**	**SI-8000-1000**	**SI-16000-2000**
Rated Sensing Ranges						
Fx, Fy	±900 lbf	±1800 lbf	±3600 lbf	±4000 N	±8000 N	±16000 N
Fz**	±1800 lbf	±3600 lbf	±7200 lbf	±8000 N	±16000 N	±32000 N
Tx, Ty, Tz	±4500 lbf-in	±9000 lbf-in	±18000 lbf-in	±500 Nm	±1000 Nm	±2000 Nm
Resolution (minimum)						
Fx, Fy	1 lbf	2 lbf	5 lbf	2 N	5 N	10 N
Fz	1 lbf	2 lbf	5 lbf	4 N	10 N	20 N
Tx, Ty	2 lbf-in	5 lbf-in	10 lbf-in	1/4 Nm	1/2 Nm	1 Nm
Tz	2 lbf-in	5 lbf-in	10 lbf-in	1/4 Nm	1/2 Nm	1 Nm
Counts Value						
Fx, Fy, Fz	8 / lbf	4 / lbf	2 / lbf	4 / N	2 / N	1 / N
Tx, Ty, Tz	4 / lbf-in	2 / lbf-in	1 / lbf-in	32 / N-m	16 / N-m	8 / N-m
Analog Output						
Analog Range						
Fx, Fy	±900 lbf	±1800 lbf	±3600 lbf	±4000 N	±8000 N	±16000 N
Fz**	±1800 lbf	±3600 lbf	±7200 lbf	±8000 N	±16000 N	±32000 N
Tx, Ty, Tz	±4500 lbf-in	±9000 lbf-in	±18000 lbf-in	±500 Nm	±1000 Nm	±2000 Nm
±5V Sensitivity						
Fx, Fy	180 lbf/V	360 lbf/V	720 lbf/V	800 N/V	1600 N/V	3200 N/V
Fz	360 lbf/V	720 lbf/V	1440 lbf/V	1600 N/V	3200 N/V	6400 N/V
Tx, Ty, Tz	900 lbf-in/V	1800 lbf-in/V	3600 lbf-in/V	100 Nm/V	200 Nm/V	400 Nm/V
±10V Sensitivity						
Fx, Fy	90 lbf/V	180 lbf/V	360 lbf/V	400 N/V	800 N/V	1600 N/V
Fz	180 lbf/V	360 lbf/V	720 lbf/V	900 N/V	1600 N/V	3200 N/V
Tx, Ty, Tz	450 lbf-in/V	900 lbf-in/V	1800 lbf-in/V	50 Nm/V	100 Nm/V	200 Nm/V
Tool Transform Factor	0.02 in/unit	0.02 in/unit	0.02 in/unit	1.25 mm/unit	1.25 mm/unit	1.25 mm/unit

** For IP68 version see caution on physical properties page.

4.12.3 Omega250 Physical Properties (Includes IP60/IP65/IP68 Versions)

	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	2.4E+6 lbf/in	420.E+6 N/m
Z-axis force (Kz)	3.2E+6 lbf/in	560.E+6 N/m
X-axis and Y-axis torque (Ktx, Kty)	27E+6 in-lbf/rad	3.0E+6 Nm/rad
Z-axis torque (Ktz)	55E+6 in-lbf/rad	6.2E+6 Nm/rad
Maximum Single-axis Load		
Fx, Fy	±36,000 lbf	±160,000 N
Fz	±74,000 lbf	±320,000 N
Tx, Ty, Tz	±180,000 lbf-in	±20,000 Nm
Tx, Ty, Tz	±220,000 lbf-in	±25,000 Nm
Weight (includes standard interface plates)		
Transducer with standard MAP plates	66 lb	30 kg
IP60	73 lb	33 kg
IP65/IP68	70 lb	32 kg

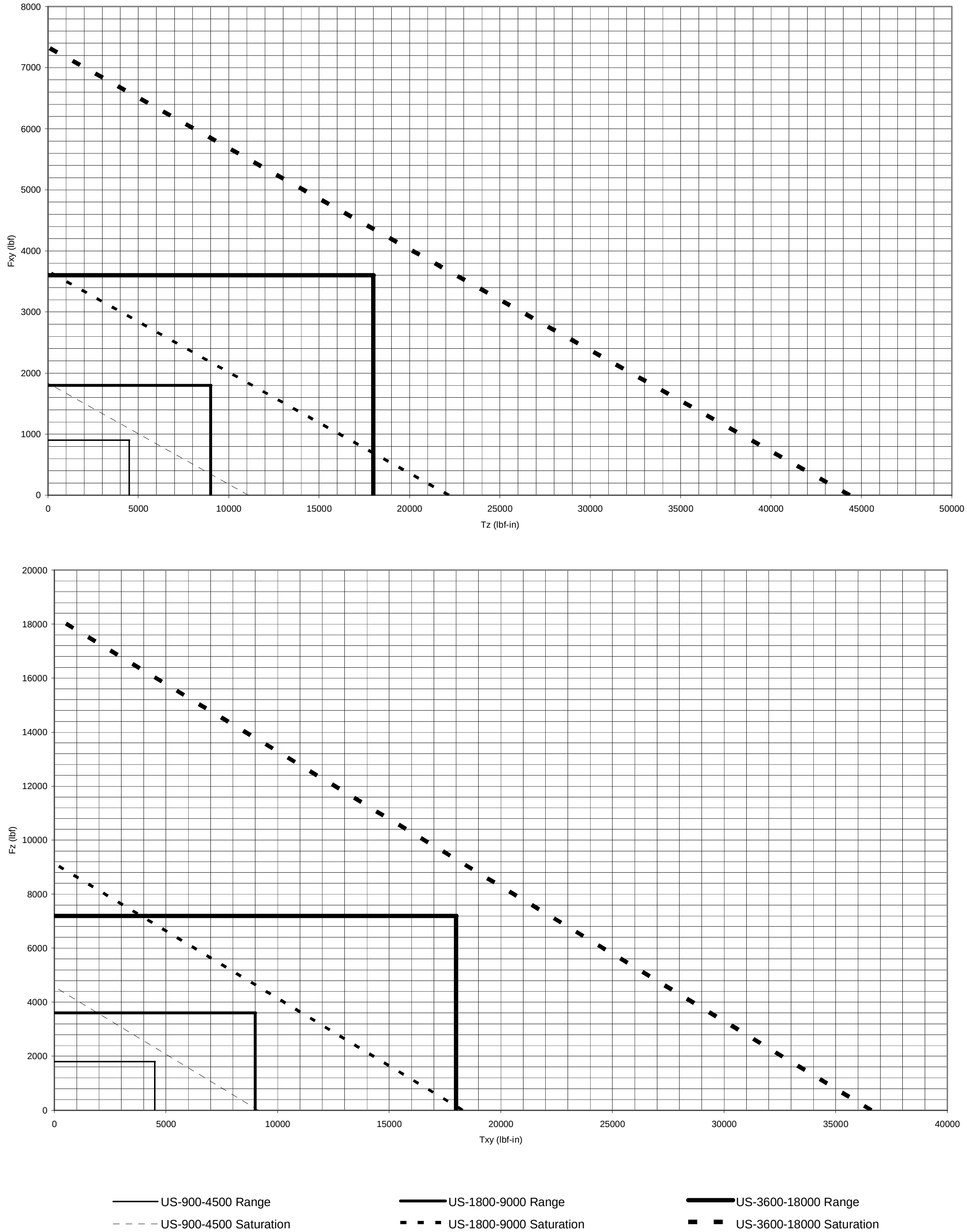
⚠ **CAUTION:**

IP68 Omega250 Fz as a Function of Submersion Depth:

When submerged, IP68 transducers exhibit a decrease in Fz range related to the submersion depth. This loss is the result of pressure-induced preloading on the transducer. The preload can be masked by biasing the transducer at the depth prior to applying the load to be measured. The following estimates are for room temperature fresh water at seal level.

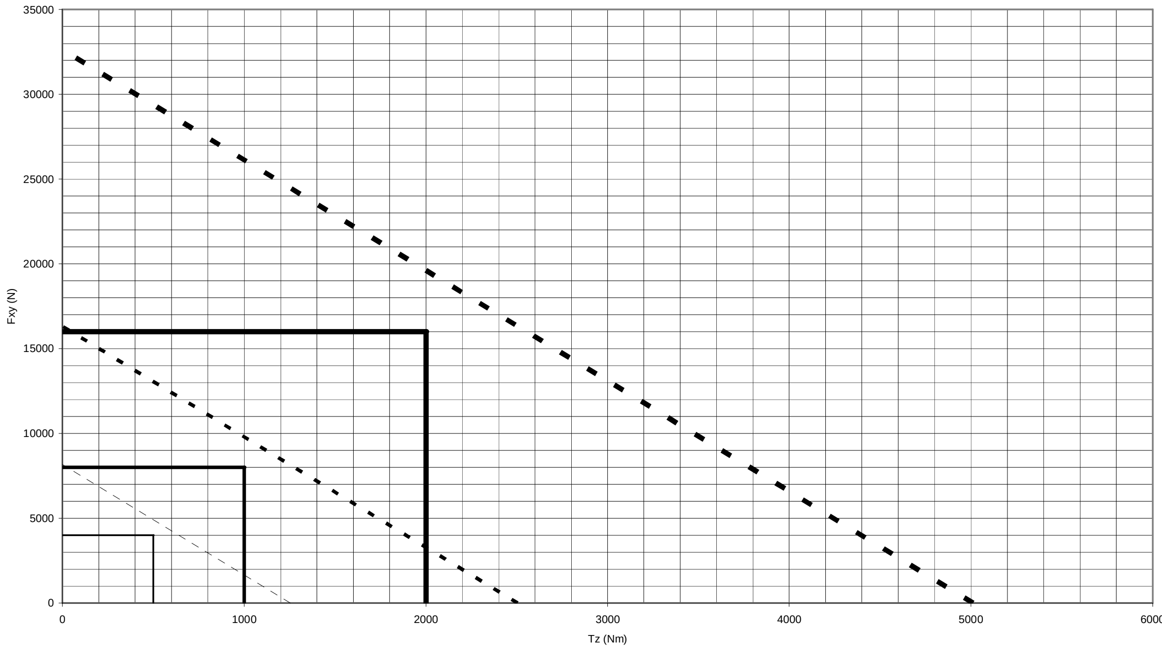
IP68 Omega250	US	Metric
Fz preload at 10m depth	- 1138 lb	- 5061 N
Fz preload at other depths	- 35 lb/ft x depthInFeet	- 506 N/m x depthInMeters

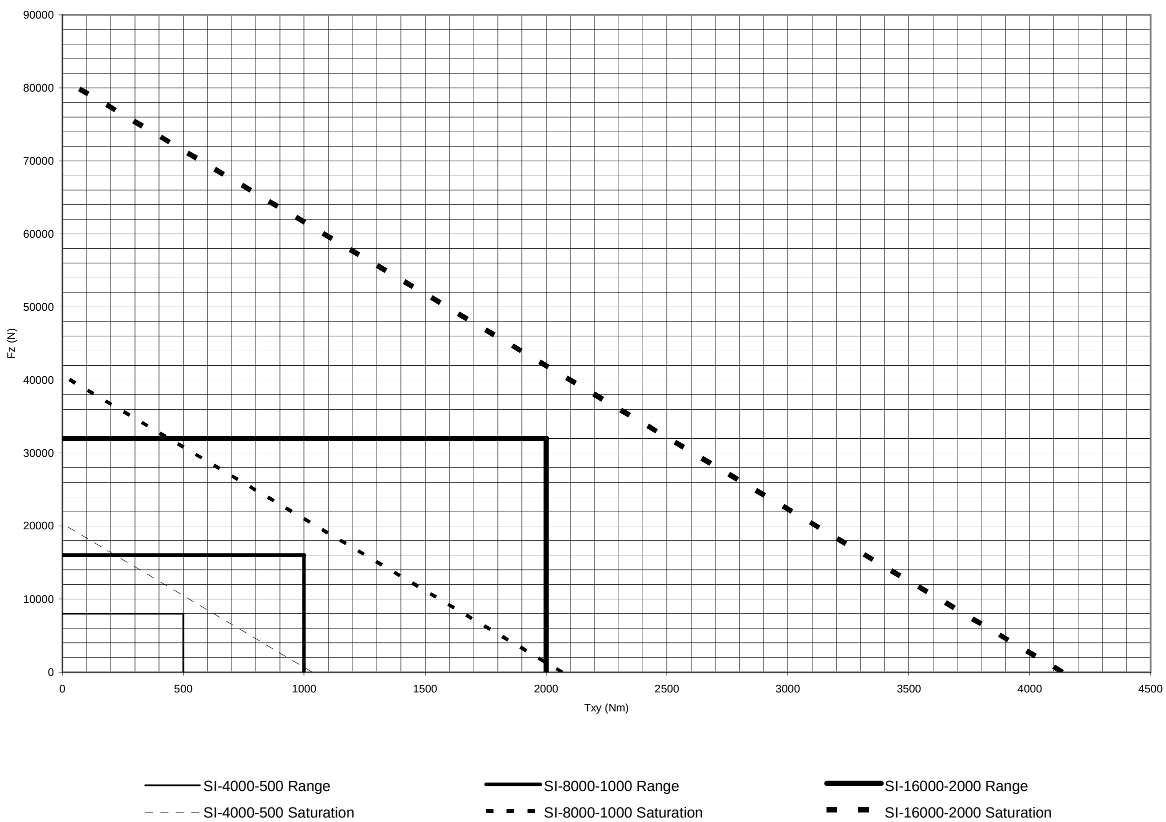
4.12.4 Omega250 (US Calibration Complex Loading) (Includes IP60/IP65/IP68 Versions)



** For IP68 version see caution on physical properties page.

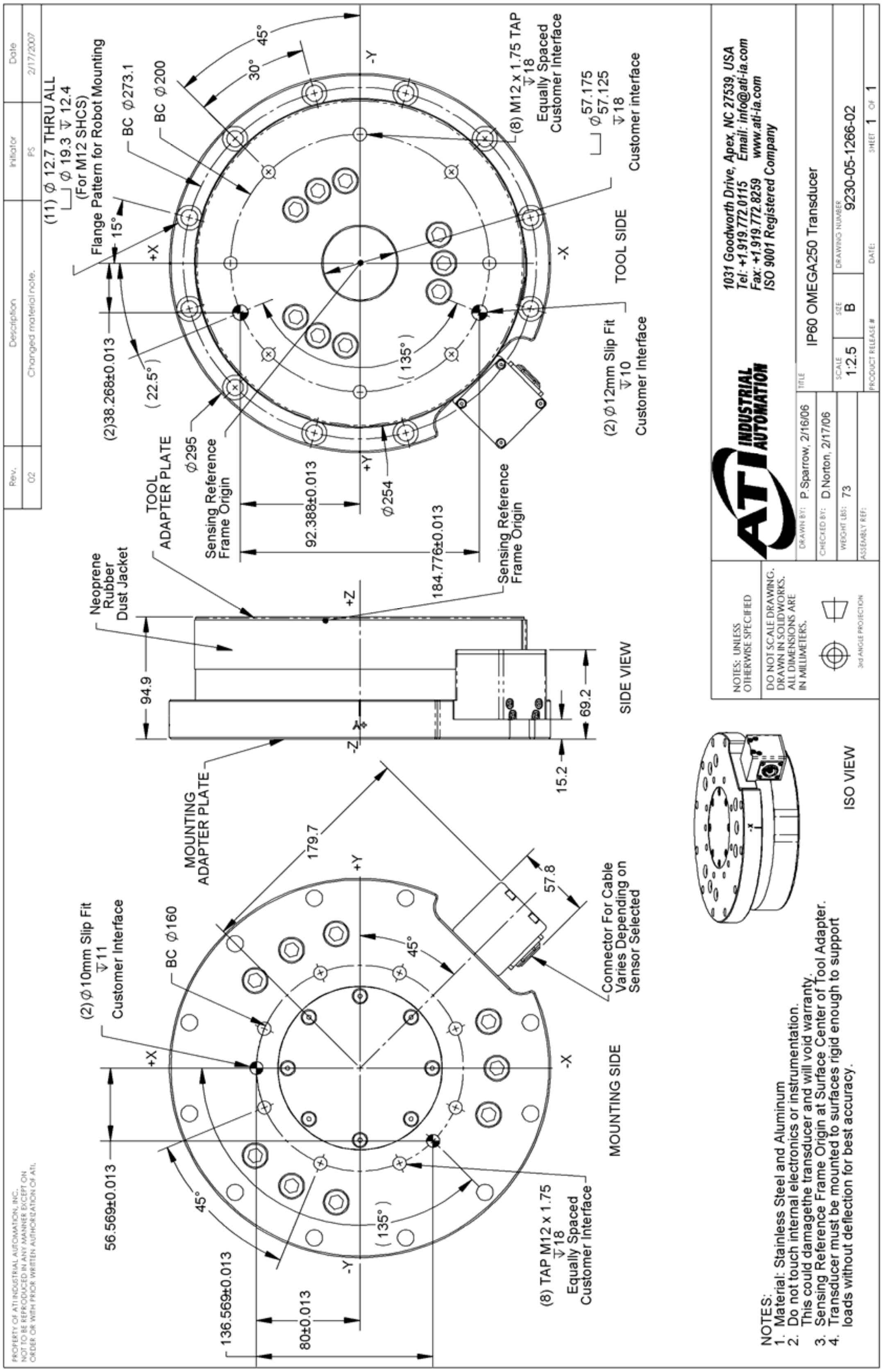
4.12.5 Omega250 (SI Calibration Complex Loading) (Includes IP60/IP65/IP68 Versions)



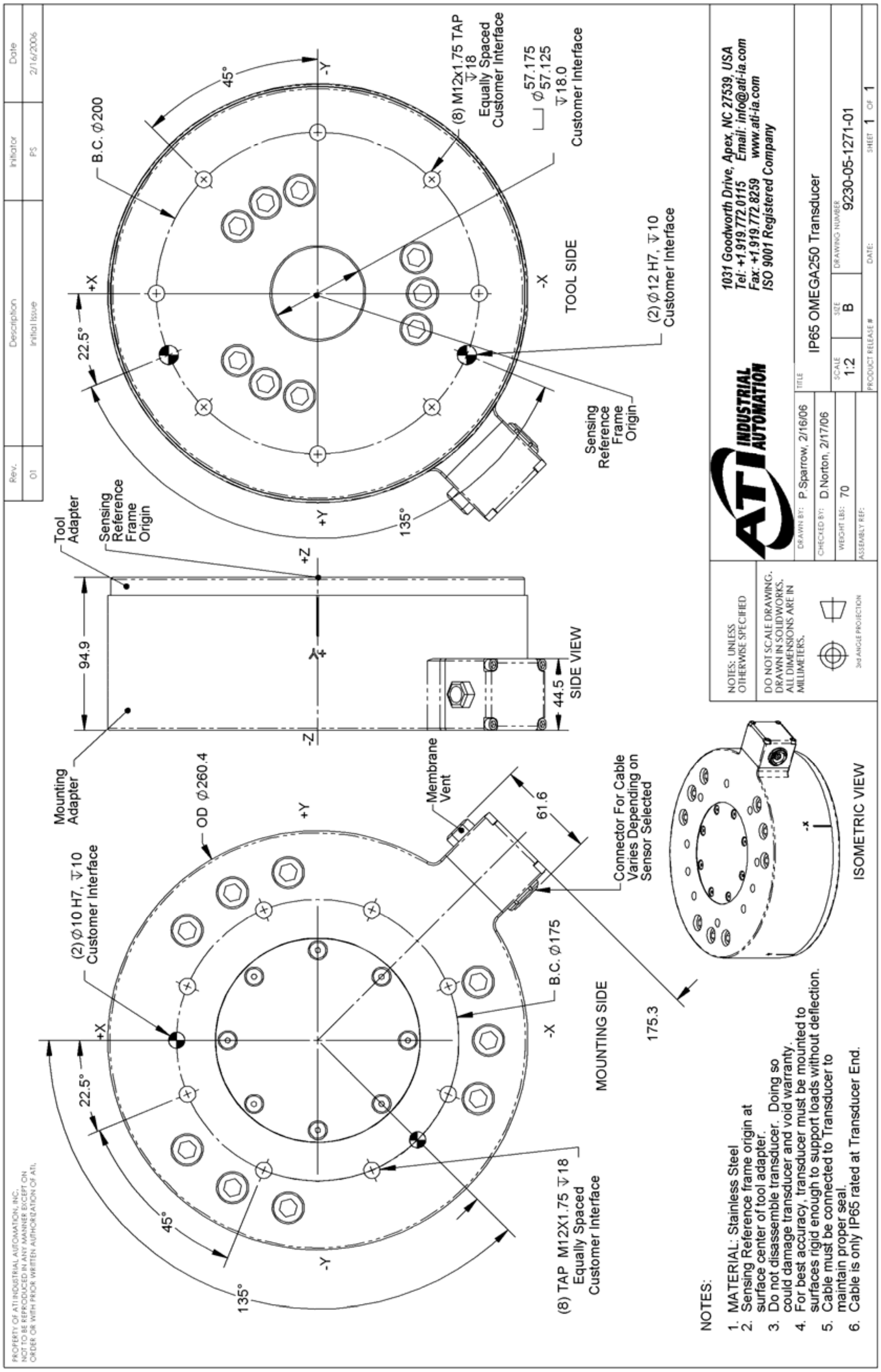


** For IP68 version see caution on physical properties page.

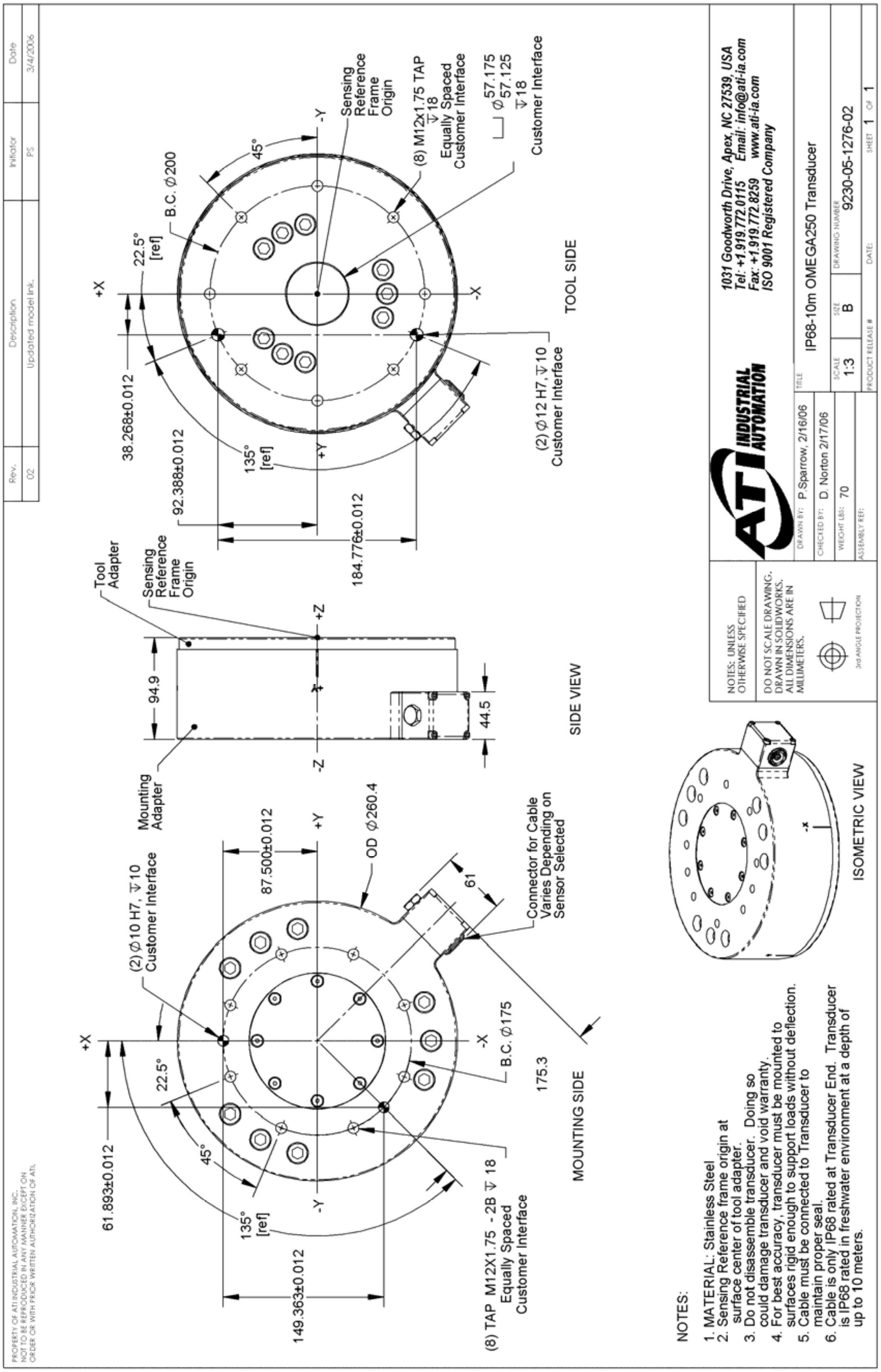
4.12.6 IP60 Omega250 Transducer



4.12.7 IP65 Omega250 Transducer



4.12.8 IP68 Omega250 Transducer



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4.13 Omega331

4.13.1 DAQ Calibration Specifications (Includes TWE and TWL Calibrations)

	US (English)			SI (Metric)		
Calibration	**US-2250-13000**	**US-4500-26000**	**US-9000-52000**	**SI-10000-1500**	**SI-20000-3000**	**SI-40000-6000**
Rated Sensing Ranges						
Fx, Fy	±2250 lbf	±4500 lbf	±9000 lbf	±10 kN	±20 kN	±40 kN
Fz	±5250 lbf	±10500 lbf	±21000 lbf	±22 kN	±44 kN	±88 kN
Tx, Ty, Tz	±13000 lbf-in	±26000 lbf-in	±52000 lbf-in	±1.5 kNm	±3 kNm	±6 kNm
Resolution (minimum)*						
Fx, Fy	1/2 lbf	1 lbf	2 lbf	1/480 kN	1/240 kN	1/120 kN
Fz	1 lbf	2 lbf	4 lbf	1/240 kN	1/120 kN	1/60 kN
Tx, Ty	3 3/4 lbf-in	7 1/2 lbf-in	15 lbf-in	3/8000 kNm	3/4000 kNm	3/2000 kNm
Tz	1 7/8 lbf-in	3 3/4 lbf-in	7 1/2 lbf-in	3/16000 kNm	3/8000 kNm	3/4000 kNm

*DAQ resolutions are typical for a 16-bit data acquisition system

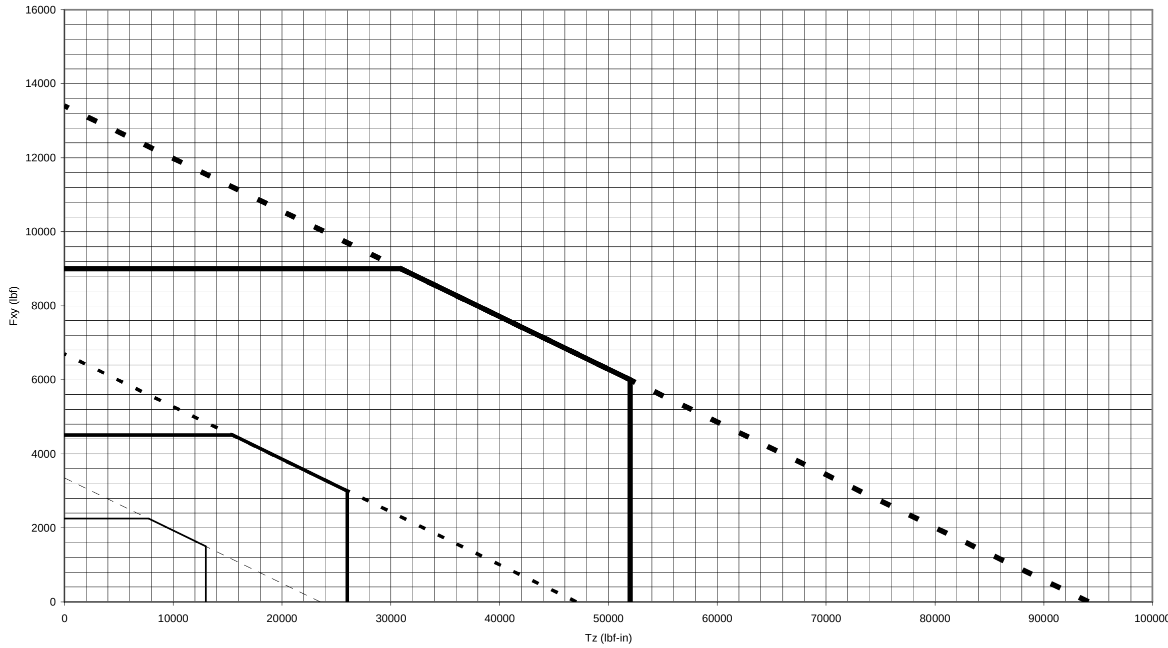
4.13.2 CTL Calibration Specifications

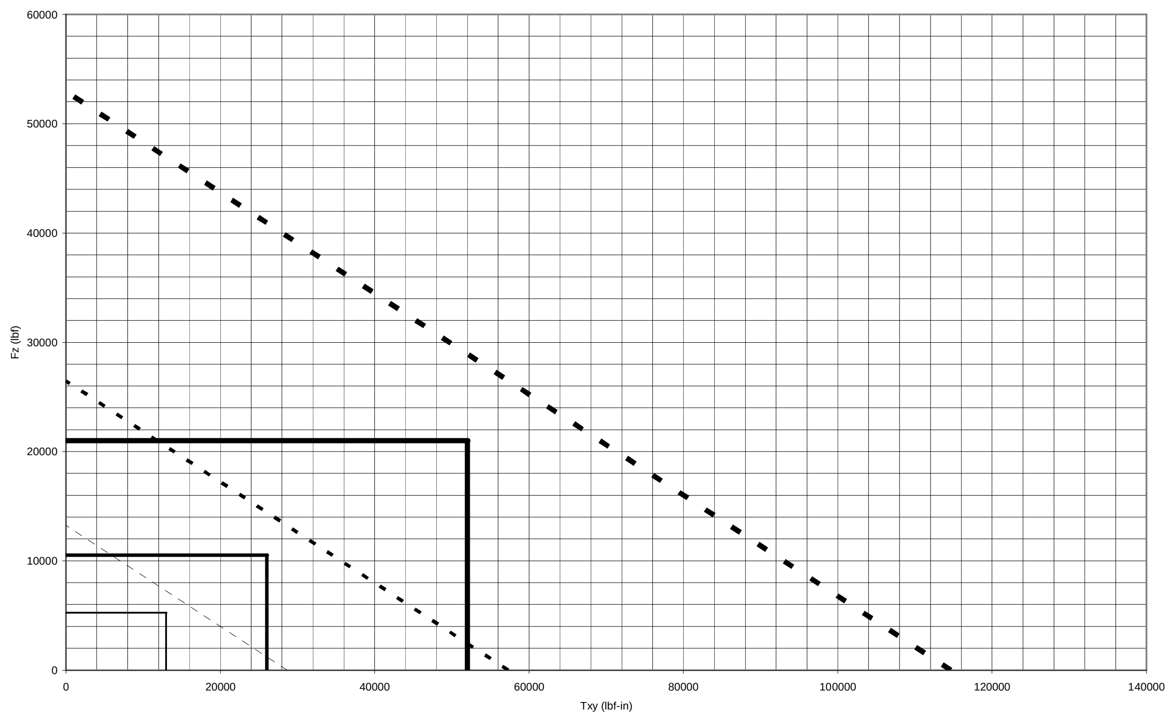
	US (English)			SI (Metric)		
Calibration	**US-2250-13000**	**US-4500-26000**	**US-9000-52000**	**SI-10000-1500**	**SI-20000-3000**	**SI-40000-6000**
Rated Sensing Ranges						
Fx, Fy	±2250 lbf	±4500 lbf	±9000 lbf	±10 kN	±20 kN	±40 kN
Fz	±5250 lbf	±10500 lbf	±21000 lbf	±22 kN	±44 kN	±88 kN
Tx, Ty, Tz	±13000 lbf-in	±26000 lbf-in	±52000 lbf-in	±1.5 kNm	±3 kNm	±6 kNm
Resolution (minimum)						
Fx, Fy	1 lbf	2 lbf	4 lbf	1/240 kN	1/120 kN	1/60 kN
Fz	2 lbf	4 lbf	8 lbf	1/120 kN	1/60 kN	1/30 kN
Tx, Ty	7 1/2 lbf-in	15 lbf-in	30 lbf-in	3/4000 kNm	3/2000 kNm	3/1000 kNm
Tz	3 3/4 lbf-in	7 1/2 lbf-in	15 lbf-in	3/8000 kNm	3/4000 kNm	3/2000 kNm
Counts Value						
Fx, Fy, Fz	32 / lbf	16 / lbf	8 / lbf	7680 / kN	3840 / kN	1920 / kN
Tx, Ty, Tz	6.4 / lbf-in	3.2 / lbf-in	1.6 / lbf-in	64000 / kNm	32000 / kNm	16000 / kNm
Analog Output						
Analog Range						
Fx, Fy	±2250 lbf	±4500 lbf	±9000 lbf	±10 kN	±20 kN	±40 kN
Fz	±5250 lbf	±10500 lbf	±21000 lbf	±22 kN	±44 kN	±88 kN
Tx, Ty, Tz	±13000 lbf-in	±26000 lbf-in	±52000 lbf-in	±1.5 kNm	±3 kNm	±6 kNm
±5V Sensitivity						
Fx, Fy	450 lbf/V	900 lbf/V	1800 lbf/V	2 kN/V	4 kN/V	8 kN/V
Fz	1050 lbf/V	2100 lbf/V	4200 lbf/V	4.4 kN/V	8.8 kN/V	17.6 kN/V
Tx, Ty, Tz	2600 lbf-in/V	5200 lbf-in/V	10400 lbf-in/V	0.3 kNm/V	0.6 kNm/V	1.2 kNm/V
±10V Sensitivity						
Fx, Fy	225 lbf/V	450 lbf/V	900 lbf/V	1 kN/V	2 kN/V	4 kN/V
Fz	525 lbf/V	1050 lbf/V	2100 lbf/V	2.2 kN/V	4.4 kN/V	8.8 kN/V
Tx, Ty, Tz	1300 lbf-in/V	2600 lbf-in/V	5200 lbf-in/V	0.15 kNm/V	0.3 kNm/V	0.6 kNm/V
Tool Transform Factor	0.05 in/unit	0.05 in/unit	0.05 in/unit	1.2 mm/unit	1.2 mm/unit	1.2 mm/unit

4.13.3 Omega331 Physical Properties

	US (English)	SI (Metric)
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	6.9E+6 lbf/in	1.2E+9 N/m
Z-axis force (Kz)	7.3E+6 lbf/in	1.3E+9 N/m
X-axis and Y-axis torque (Ktx, Kty)	81.E+6 in-lbf/rad	9.2E+6 Nm/rad
Z-axis torque (Ktz)	210.E+6 in-lbf/rad	24.E+6 Nm/rad
Maximum Single-axis Load		
Fx, Fy	±57,000. lbf	±250,000. N
Fz	±110,000. lbf	±510,000. N
Tx, Ty, Tz	±280,000. lbf-in	±32,000. Nm
Tx, Ty, Tz	±400,000. lbf-in	±45,000. Nm
Weight (includes standard interface plates)		
Transducer with standard aluminum MAP plates	104 lb	47 kg

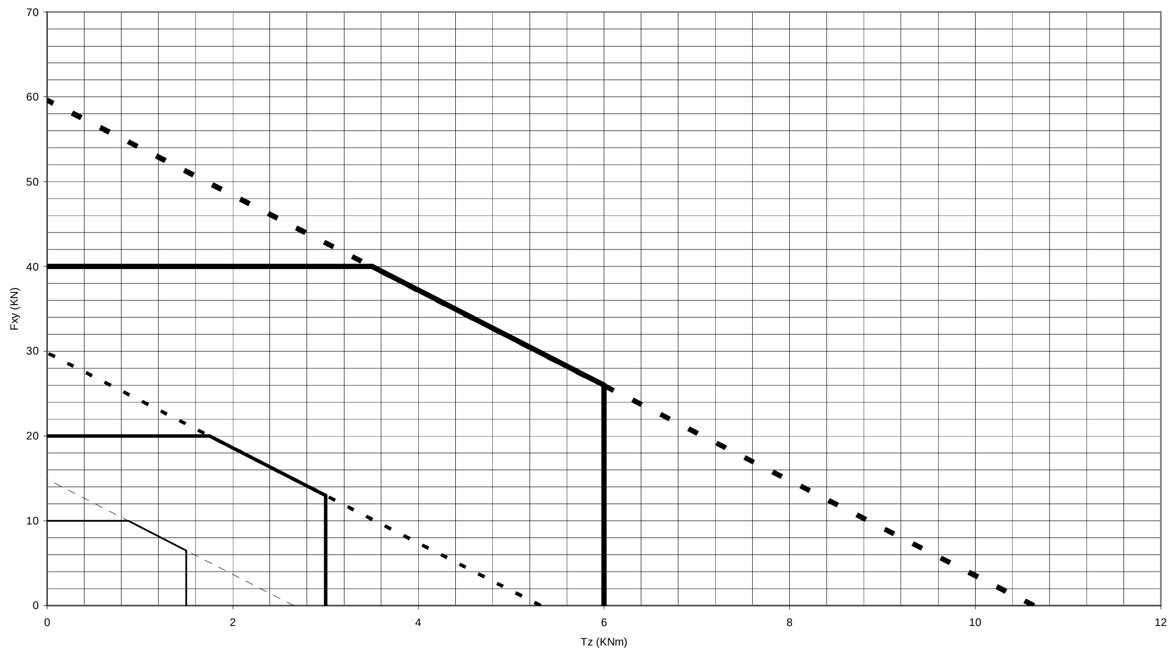
4.13.4 Omega331 (US Calibration Complex Loading)

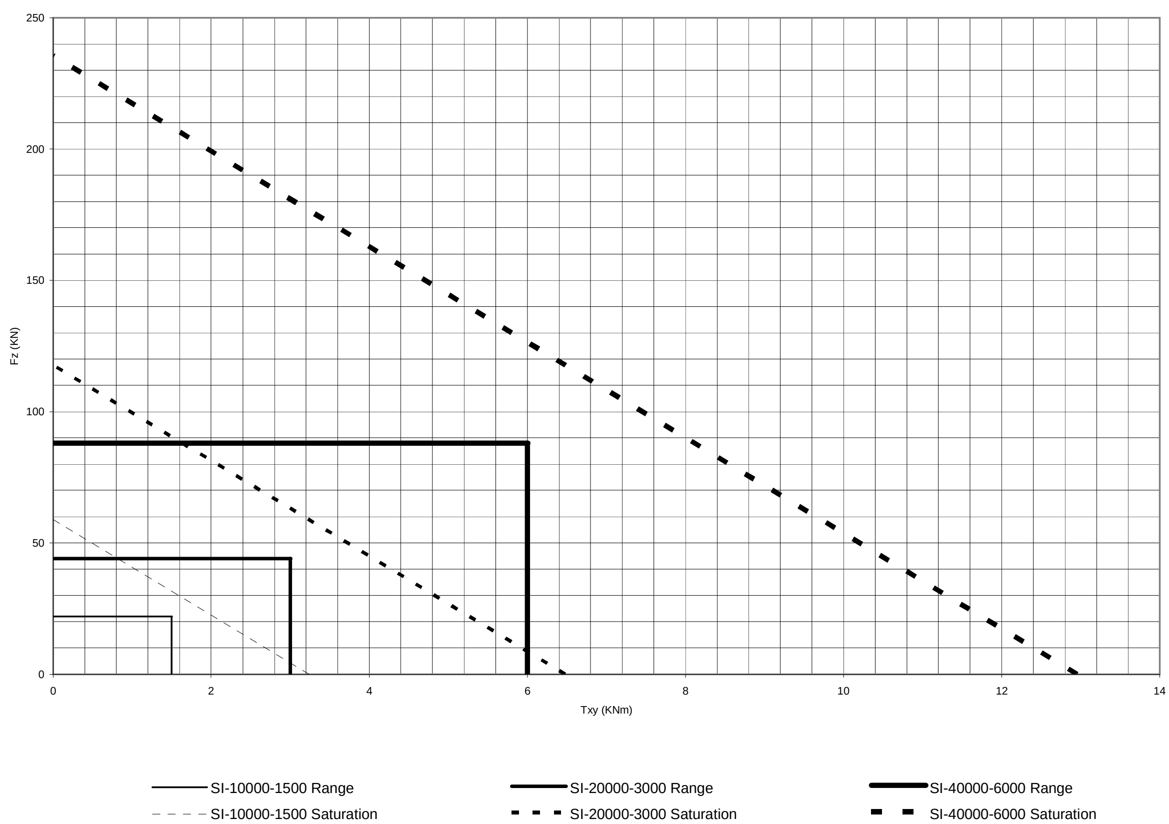




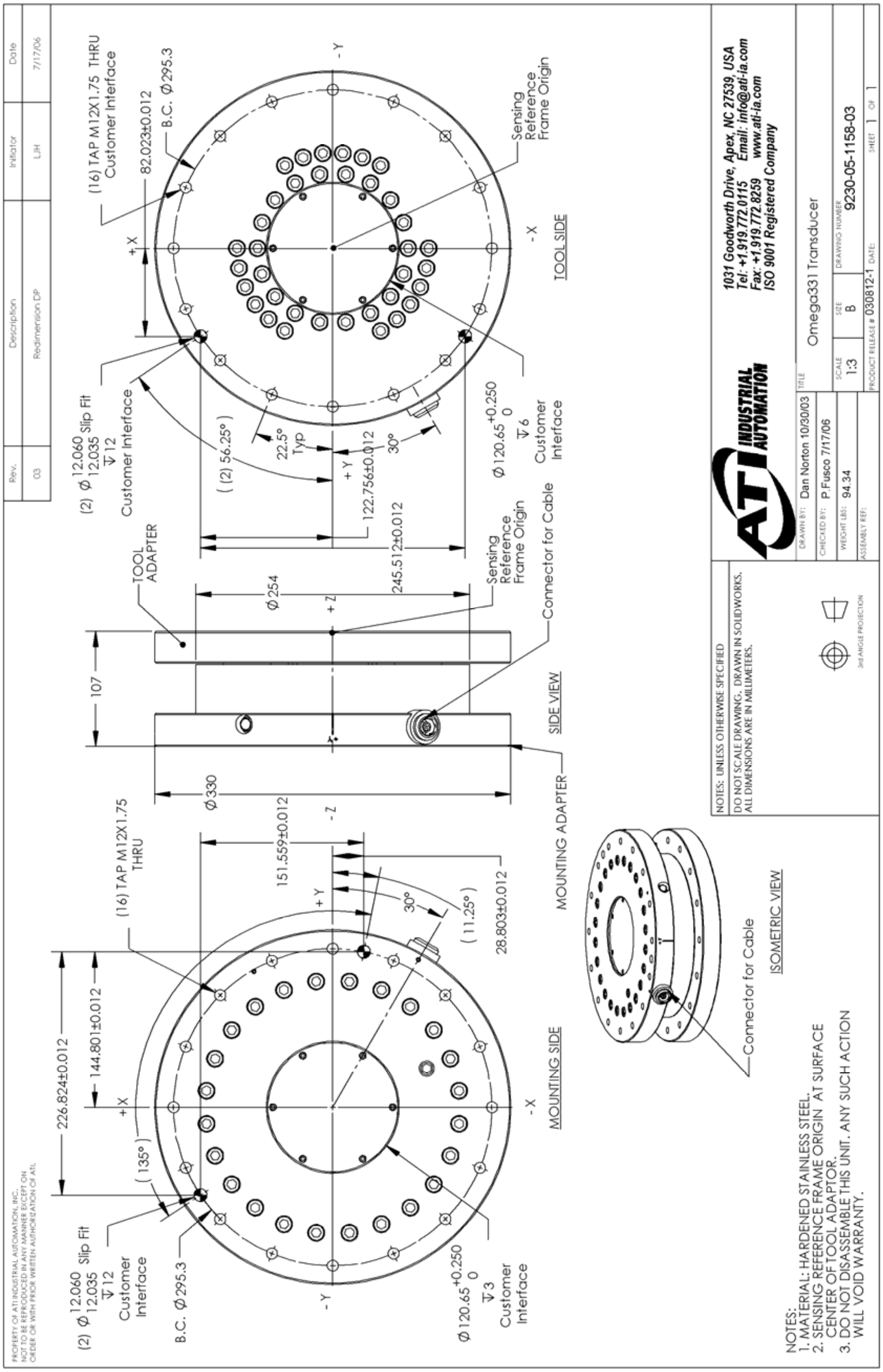
US-2250-13000 Range
US-2250-13000 Saturation
US-4500-26000 Range
US-4500-26000 Saturation
US-9000-52000 Range
US-9000-52000 Saturation

4.13.5 Omega331 (SI Calibration Complex Loading)





4.13.6 Omega 331 Transducer



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5. Terms and Conditions of Sale

The following Terms and Conditions are a supplement to and include a portion of ATI's Standard Terms and Conditions, which are on file at ATI and available upon request.

ATI warrants to Purchaser that force torque sensor products purchased hereunder will be free from defects in material and workmanship under normal use for a period of one year from the date of shipment. This warranty does not cover components subject to wear and tear under normal usage or those requiring periodic replacement. ATI will have no liability under this warranty unless: (a) ATI is given written notice of the claimed defect and a description thereof within thirty (30) days after Purchaser discovers the defect and in any event not later than the last day of the warranty period; and (b) the defective item is received by ATI not later ten (10) days after the last day of the warranty period. ATI's entire liability and Purchaser's sole remedy under this warranty is limited to repair or replacement, at ATI's election, of the defective part or item or, at ATI's election, refund of the price paid for the item. The foregoing warranty does not apply to any defect or failure resulting from improper installation, operation, maintenance or repair by anyone other than ATI.

ATI will in no event be liable for incidental, consequential or special damages of any kind, even if ATI has been advised of the possibility of such damages. ATI's aggregate liability will in no event exceed the amount paid by purchaser for the item which is the subject of claim or dispute. ATI will have no liability of any kind for failure of any equipment or other items not supplied by ATI.

No action against ATI, regardless of form, arising out of or in any way connected with products or services supplied hereunder may be brought more than one year after the cause of action accrued.

No representation or agreement varying or extending the warranty and limitation of remedy provisions contained herein is authorized by ATI, and may not be relied upon as having been authorized by ATI, unless in writing and signed by an executive officer of ATI.

Unless otherwise agreed in writing by ATI, all designs, drawings, data, inventions, software and other technology made or developed by ATI in the course of providing products and services hereunder, and all rights therein under any patent, copyright or other law protecting intellectual property, shall be and remain ATI's property. The sale of products or services hereunder does not convey any express or implied license under any patent, copyright or other intellectual property right owned or controlled by ATI, whether relating to the products sold or any other matter, except for the license expressly granted below.

In the course of supplying products and services hereunder, ATI may provide or disclose to Purchaser confidential and proprietary information of ATI relating to the design, operation or other aspects of ATI's products. As between ATI and Purchaser, ownership of such information, including without limitation any computer software provided to Purchaser by ATI, shall remain in ATI and such information is licensed to Purchaser only for Purchaser's use in operating the products supplied by ATI hereunder in Purchaser's internal business operations.

Without ATI's prior written permission, Purchaser will not use such information for any other purpose or provide or otherwise make such information available to any third party. Purchaser agrees to take all reasonable precautions to prevent any unauthorized use or disclosure of such information.

Purchaser will not be liable hereunder with respect to disclosure or use of information which: (a) is in the public domain when received from ATI; (b) is thereafter published or otherwise enters the public domain through no fault of Purchaser; (c) is in Purchaser's possession prior to receipt from ATI; (d) is lawfully obtained by Purchaser from a third party entitled to disclose it; or (f) is required to be disclosed by judicial order or other governmental authority, provided that, with respect to such required disclosures, Purchaser gives ATI prior notice thereof and uses all legally available means to maintain the confidentiality of such information.