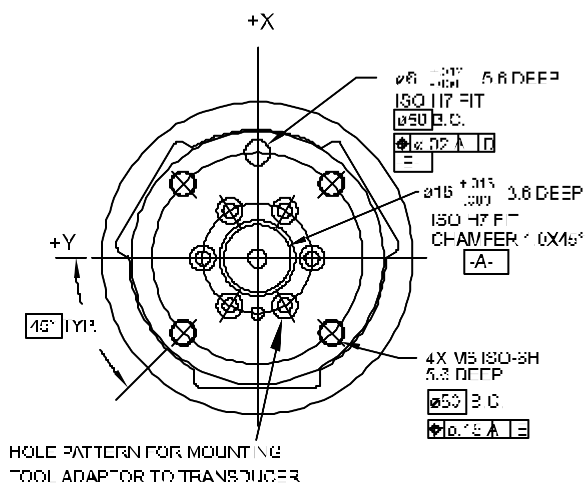
Installation and Operations Manual for Stand-alone F/T Sensor Systems

Intelligent Multi-axis
Force/Torque Sensor System



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Manual PN 9610-05-1001-18
Firmware Version 5.0

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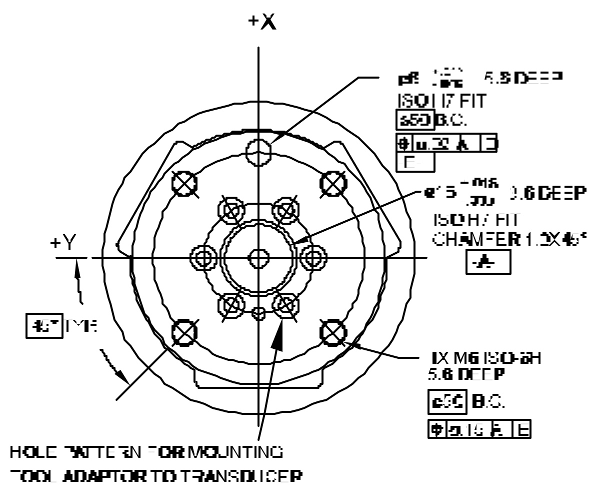

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Published in the USA.
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FCC Compliance - Class B

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.

CE Compliance

This device complies with EMC Directive 89/336/EEC and FCC Title 47 CFR, Part 15 Subpart B and conforms to the following standards: ANSI C63.4:1992, CISPR 22: 1993, Amt. 1 ,2, EN 61000-4-2: 1995, EN 61000-4-3:1997, EN 61000-4-4:1995, EN 61000-4-5:1995, EN 61000-4-6:1996, EN 61000-4-8:1994, EN 61000-4-11:1995.

ECC Compliance

This device complies with Council Directive: 73/23/ECC and conforms to Cenelec Standard EN 60101-1: 1993.

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Aside...

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

1. Serial number.
2. Transducer model (e.g., Nano17, Gamma, Theta, etc.).
3. Calibration (e.g., US-15-50, SI-65-6, etc.)
4. Accurate and complete description of the question or problem.
5. Software revision. This is output in the power-on header message and can also be found on the microprocessor inside the F/T stand-alone controller.

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

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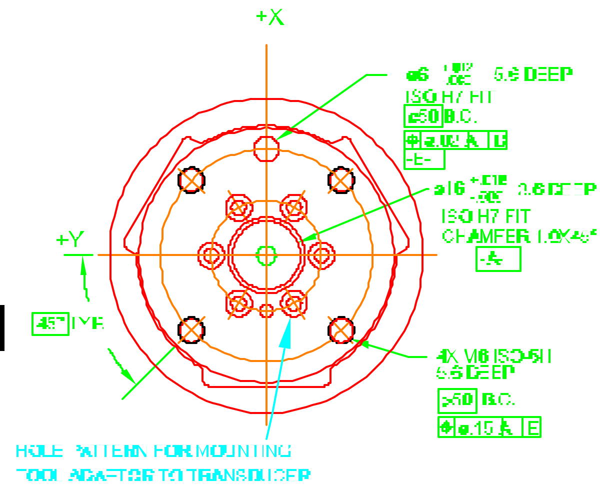
Getting Started



Section **Page**

1.1 INTRODUCTION

This section gives instructions for setting up the F/T system. Final installation is covered in Section 2. After setting up the system, a test is performed to check for problems. It is possible to start learning the commands described in Section 4 before starting the final installation.

Warning...

The Force/Torque sensor, the calibration matrix loaded into the stand-alone and the mux 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 / Torque data will be incorrect. Please do not mix the system components.

1.2 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 [see Figure 1.1]:
  - Transducer
  - Transducer cable (for 9105-T transducers)
  - Mux box (9105-TW transducers only)
  - Mux cable (for 9105-TW transducers only)
  - Stand-alone F/T controller
  - Power cord

- 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
  - Mux box; replaces electronics in transducer (for 9105-TW transducers)
  - Mux cable; used only with Mux box

- Analog output card (installs in stand-alone F/T controller)
- Serial software utilities for IBM PC compatible computers

> ***Aside...***
>
> If your sensor has special features check Appendix C for additional information.

> ***Warning...***
>
> The transducer is susceptible to damage from electrostatic discharge whenever it is not connected to the F/T system. Do not touch the electronics or the connector pins when handling the transducer.
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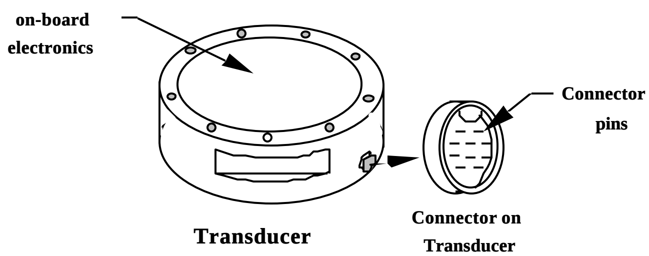
> 
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1.3 SYSTEM COMPONENTS DESCRIPTION

Transducer

The transducer is a compact, rugged, monolithic structure that converts force and torque into analog strain gage signals for the F/T controller. 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 1.1 shows the transducer with a standard tool adaptor.

- If your system has the Dual Gain Calibration Option see Appendix D for instructions on selecting the individual calibrations.

For further information not in this section see:
- *Appendix A* for specifications (i.e. resolution, weight).
- *Appendix B* for mechanical drawings.
- *Section 2, Final Installation*, for mounting and cable routing.

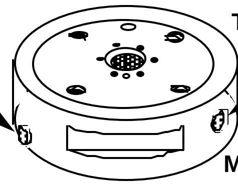

Figure 1.1 Transducer

> ***Aside...***
>
> The transducer is designed to withstand extremely high overloading through its use of strong materials and quality silicon strain gages. The Nano, Mini and Omega 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.

Transducer Cable

The high-flex transducer cable is electrically shielded to protect transmission between the transducer (or mux box) and the F/T controller. The transducer or mux connector is molded to one end of the cable, and a 15-pin D-subminiature connector on the other end is for interfacing to the F/T controller [See Figure 1.2].

For further information not in this section see:
• *Section 2, Final Installation*, for cable routing.

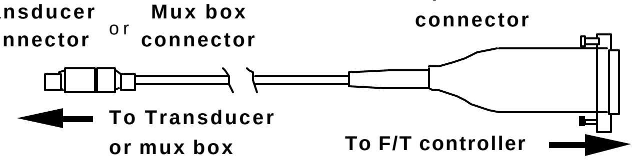

Figure 1.2 Transducer cable

F/T Controller

The primary function of the F/T controller is to convert strain gage data to Cartesian force/torque components. Communication can be done through the serial I/O, the discrete I/O, or the optional analog output.

For further information not in this section see:
• *Section 3, How It Works*, for the hardware flow chart.
• *Section 5 and 6* for the electrical specifications and the connector pin-outs.
• *Appendix B* shows the mechanical dimensions of the controller chassis and mux box.

F/T Commands

The stand-alone controller allows the user to issue commands to control the F/T system. F/T commands are entered through the serial .
For further information not in this section see:
• *Section 3, How It Works*, for flowchart.
• *Section 4, Commands*, for descriptions of the stand-alone controller commands.

Interface Plates

The transducer comes with a standard mounting adaptor to mechanically attach the transducer. The transducer also has a standard tool adaptor with an ISO 9409-1 (for Gamma, Delta, and Theta models) interface for attaching your tool.

The mounting adaptor consists of:
- Mounting adaptor plate
- Mounting screws

For Gamma and Delta transducers the mounting adaptor can be replaced with the optional mounting ring-plug adaptor [see Figure 2.2] which consists of:
- Mounting ring
- Mounting plug
- Mounting flange
- Mounting screws

For Gamma and Delta transducers the standard tool adaptor can be replaced with the optional tool ring-plug adaptor [see Figure 2.3] which consists of:
- Tool ring
- Tool plug
- Tool flange
- Tool screws

For further information not in this section see:
• *Section 2, Installation*
• *Appendix B, Mechanical Layout*

Optional Analog Output

An optional analog option board is available with the F/T system. The analog port provides high speed analog output.
For further information not in this section see:
• *Section 3, How It Works.*
• *Section 6, Optional Analog Output*

1.4 CONNECTING THE SYSTEM COMPONENTS

Transducer Cable Interfacing

The F/T normally uses a custom 12-pin transducer connector [see Figure 1.3], except for the Nano and Mini F/T which are hardwired.

Insert the transducer connector 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.
- Push the connector from the black rubber boot until it seats into the port with a click.

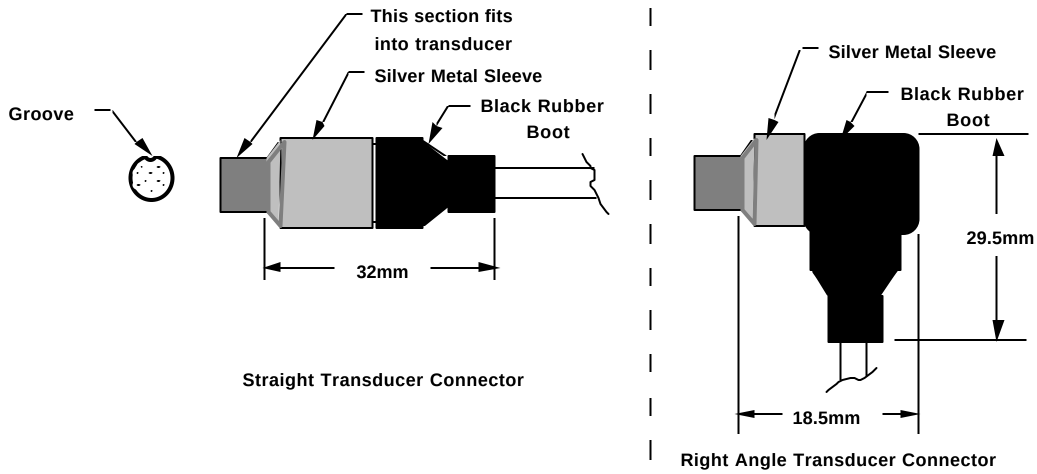

Figure 1.3 Transducer connector as straight or right angle

Disconnect the transducer connector from the transducer port as follows:

•Pull the **silver metal sleeve** on the transducer connector until the connector disconnects.

Warning...

- 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**.
- Larger transducers have removable cables. Do not attempt to disconnect these transducer cables by pulling on the cable itself or the black connector boot; this can damage your system. To disconnect these connectors, pull on the metal sleeve on the cable's connector.

Aside...

Cables that mate with our transducers lock positively to the transducer to ensure the two stay mated even through the most rigorous of movements. The small, round cable connector has four spring latches that lock into a groove in the transducer connector.

Connect the 15-pin D-subminiature connector [see Figure 1.2] to the transducer port on the F/T controller. Tighten the screws on the connector for positive locking if needed.

Serial Port Interfacing

The following instructions are for connecting a serial device (i.e. personal computer, Hyper Terminal in Windows Accessories, RS-232 terminal, etc.) to communicate with the F/T controller:

- The user must provide the serial device.
- The user must provide a serial port cable with a male 9-pin D-subminiature connector on one end for connecting to the F/T controller and a connector to mount to the serial device.
- See *Section 5* for the F/T Controller's serial port pin-out [see Tables 1.1 and 1.2 for connection information].

	F/T Stand-alone Controller RS-232 port	**9-pin Computer or Terminal RS-232 Port**
Equipment Connector Type	Male 9-pin D-Subminiature	Male 9-pin D-Subminiature
Cable Connector Type	Female 9-pin D-Subminiature	Female 9-pin D-Subminiature
Ground Signal	pin 5	pin 5
F/T Transmit Signal	pin 3	pin 2
F/T Receive Signal	pin 2	pin 3

Table 1.1 Serial port interfacing to a 9-pin RS-232 port

	F/T Stand-alone Controller RS-232 port	**25-pin Computer or Terminal RS-232 Port**
Equipment Connector Type	Male 9-pin D-Subminiature	Female 25-pin D-Subminiature
Cable Connector Type	Female 9-pin D-Subminiature	Male 25-pin D-Subminiature
Ground Signal	pin 5	pin 7
F/T Transmit Signal	pin 3	pin 3
F/T Receive Signal	pin 2	pin 2

Table 1.2 Serial port interfacing to a 25-pin RS-232 port

- Select the serial device attributes: 8-bit transmission with no parity and one stop bit.
- Select baud rate on F/T controller [see Figure 1.4] to match the baud rate of the Serial Device. The baud rate is factory preset to 9600.

Using Hyper Terminal in Windows 9X/NT/2000 for Serial Communications

Hyper Terminal can be found in the Start menu under Programs / Accessories Communications. Note: If the program is not present you will need to install it from Windows setup. Hyper Terminal is located as a communications options. Start Hypertrm.exe to create a new connection, select which com port you are using. Ex. Connect using: Direct to Com 1. And set the Port Settings to the following values to communicate with the factory controller setup.

- Bits per second : 9600
- Data bits : 8
- Parity : None
- Stop bits : 1
- Flow control : Xon/Xoff

⚠ *Warning...*

Always turn off the power switch and unplug the F/T controller's power cord before removing the F/T controller's cover to prevent electrical shock.

⚠ *Warning...*

The F/T controller's printed circuit board is susceptible to damage from static discharge. If possible, work at an anti-static workstation and ground yourself before touching the printed circuit board.

⚠ *Caution...*

The controller contains a lithium battery. The battery must be disposed of per local regulations.

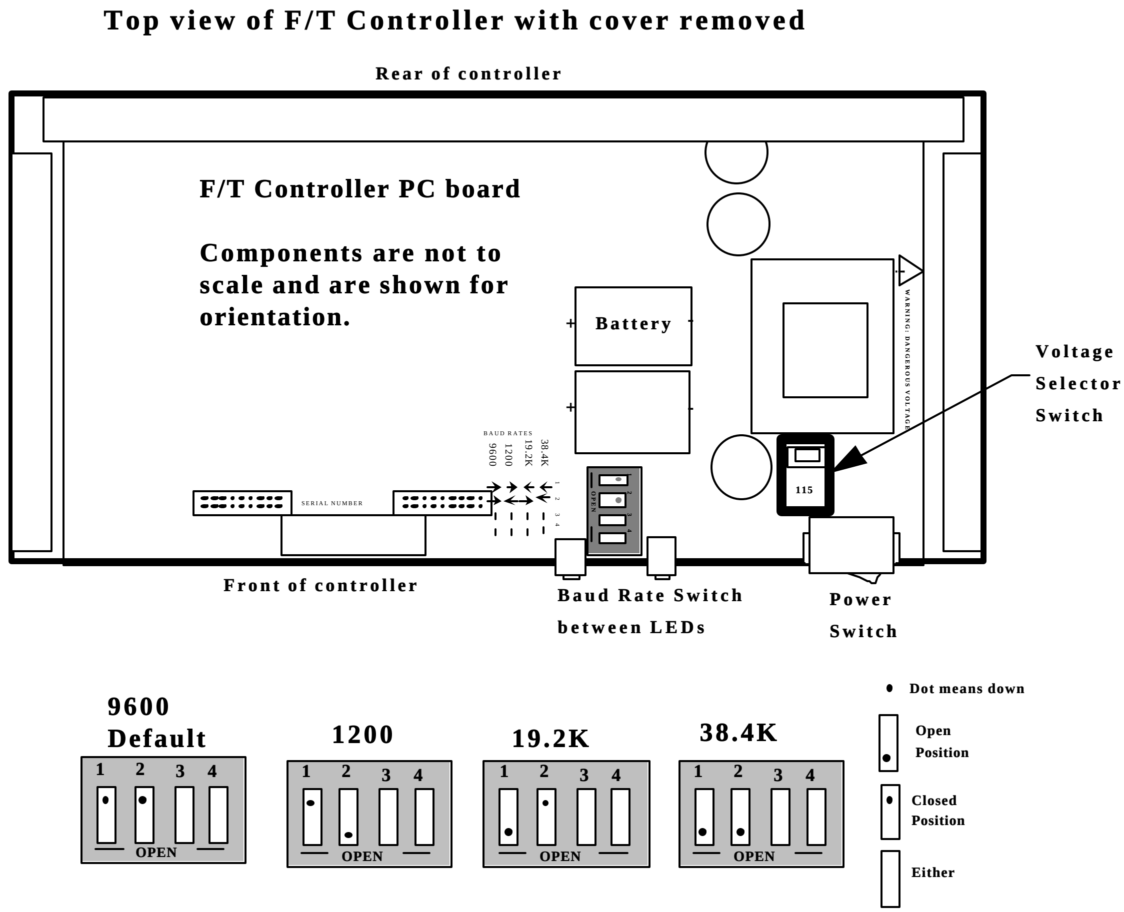

Figure 1.4 Location of the baud rate and voltage selector switches on F/T controller

Power Cord Connection

- Verify that the voltage rating is correct for your facility. See label attached under power socket. If necessary change the F/T Controller's voltage input to either 115V or 230V [see Figure 1.8 for locating the voltage selector switch]. **Turn off the power and disconnect the power cord from the F/T controller's power socket before removing the cover.**
- Turn the power switch to the off position.
- Plug the power cord into the F/T controller's power socket.
- Plug the power cord into a AC outlet.

1.5 TESTING THE F/T SYSTEM

Turning On the F/T Controller

- With the F/T system connected as described in *Section 1.4*, turn the power switch on.
- The green power LED will turn on and glow green.

- The red LED will blink on and off to verify that the diagnostic checks have passed. If the red LED stays on this signifies an error.
- A header message will appear on the serial device [See Figure 1.5].
- A “>” prompt will appear after the header message.

NOTE: Please see Appendix A of this manual for actual force, torque, and count values for your sensors calibration. There may be rounding in the Header message displayed for your system. Header Displays: 5, Actual: 4.8

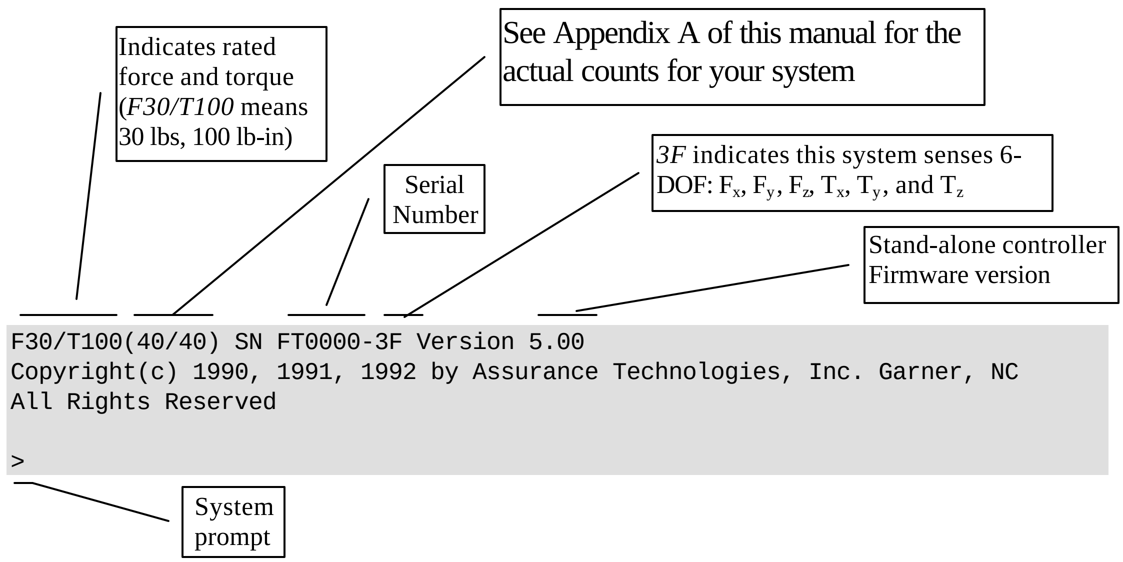

Figure 1.5 Header message and prompt

> ***Aside...***
>
> 1. <CR> indicates a carriage return (enter) character.
> 2. Commands entered by the user are displayed as bold.
> 3. If you experience problems check your electrical connections (see *Section 7, Troubleshooting Guide*) and commands (see *Section 4, Commands*).
> 4. Commands are not case sensitive so they may entered in upper- or lower-case.

Warm Start, ^W

- At the prompt type Control-W, ^**W**.
- The F/T system is reset and the screen displays the header message and prompt.

Reset Button

- Push the reset button on the front panel. The button is recessed inside the F/T controller chassis. Use a small object to push the button.
- The F/T system is reset and the screen displays the header message and prompt.

Output ASCII Force Vector (Serial Port) and Biasing

- At the prompt type **CD A<CR>**. This selects the ASCII format output.

- At the prompt type **CD R<CR>**. This selects the resolved force/torque data for output instead of the strain gage data.
- At the prompt type **QS<CR>**. Continuous output of the resolved data will begin scrolling across the screen. Touch the transducer front plate and note how the force/torque values change. See the transducer drawing in *Appendix B, Mechanical Layout*, for the sensor frame to locate the X, Y, and Z orientation on the transducer.
- Type **SB<CR>**. The data will stop and the prompt will return. The resolved data has been biased. Repeat the command **QS<CR>**. The resolved force/torque data will read close to zero.
- Type **<CR>**. The data will stop and the prompt will return.

Using the Zip Macro Start-up, ZC

- Type **ZC 0, "CD A; CD R; QS"<CR>**. This stores the commands within the double quote into the start-up macro.
- Reset the system by any of the three methods shown (e.g. Control-W).
- The commands execute at the end of the header message.
- Type **<CR>** to halt the output. The prompt will return to the screen.
- Type **ZC 0, ""<CR>**. This will clear the start-up macro.
- Reset the F/T system. The header message will appear with the prompt and without any commands being executed.

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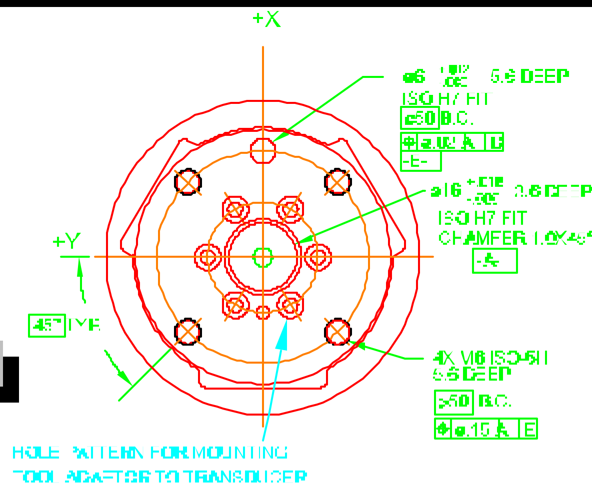
2

Installation



Section **Page**

2.1 INTRODUCTION

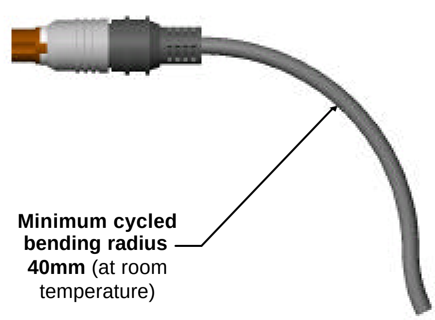
This section will assist the user in mounting the transducer, your tool, and the transducer cable.

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 *Section 1.4* for the transducer cable interfacing. If the desired application results in the cable-rubbing then use a plastic spiral wrap for protection.

Warning...

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 temperatures.

Warning...

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

2.3 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 and Omega transducers have mounting and tool adaptors which cannot be removed, so only method III can be used.** A detailed description is given on the following pages and a brief description is given below:

Transducer Mounting Method I: Uses the standard mounting adaptor to attach the transducer. You must machine the bolt pattern of your device (i.e. robot) into the mounting adaptor. You will not be able to use the mounting adaptor 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.

Transducer Mounting Method II: Uses the optional mounting ring-plug adaptor as a replacement for the standard mounting adaptor. You must machine the mounting plug to attach to your device. The mounting ring-plug adaptor has the benefit of allowing the transducer to be connected and disconnected by hand (disconnecting may require 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 adaptor will work. If the bolt pattern is larger than the plug, use method III.

Transducer Mounting Method III: Use your own interface plate to bolt directly to the transducer or (for the Nano, Mini or Omega models) the mounting adaptor.

Use *Appendix B, Mechanical Layout,* for 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 adaptor plates. The F/T system's default sensor frame sets the transducer's point of origin at the center of the mounting adaptor's surface. See *Appendix B, Mechanical Layout*, for drawings showing the default point of origin.

Transducer Mounting Method I, Standard Mounting Adaptor

Use the mounting adaptor 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 ensure that after the mounting adaptor is attached to the robot (or other device) you will have access to the mounting screws for attaching the transducer.

- Machine the mounting adaptor plate for attaching to your robot (or other device). Mounting adaptor plate dimensions are shown in *Appendix B, Mechanical Layout* [see Figure 2.1]. **All user-supplied screws must be flush with the inside of the mounting adaptor to ensure proper clearance for the electronics inside the transducer.**
- Attach the mounting adaptor to the robot (or other device). Attach the transducer to the mounting adaptor 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).

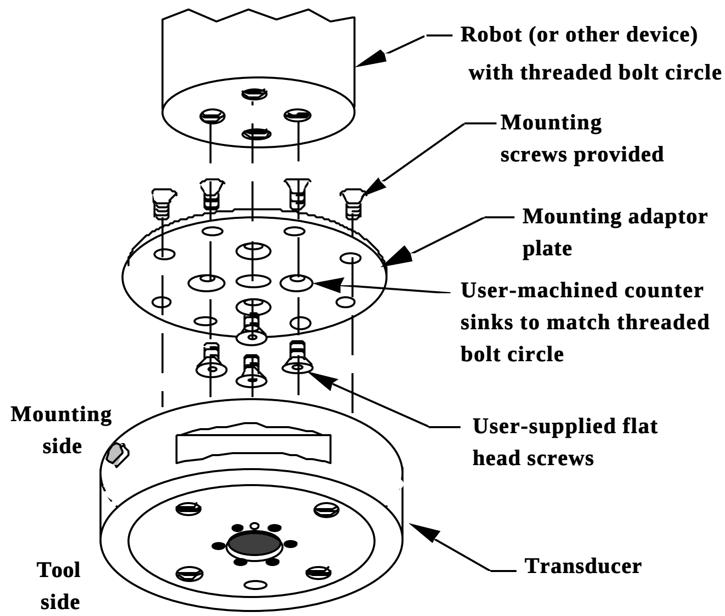


Figure 2.1 Attaching the transducer with the mounting adaptor

Transducer Mounting Method II, Mounting Ring-plug Adaptor

- 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 mounting ring
- Machine the mounting plug for attaching to your robot (or other device). Mounting plug dimensions are shown in *Appendix B* [see Figure 2.2].
- Attach the mounting plug, then attach the transducer to the mounting plug using the attached mounting ring and flange.

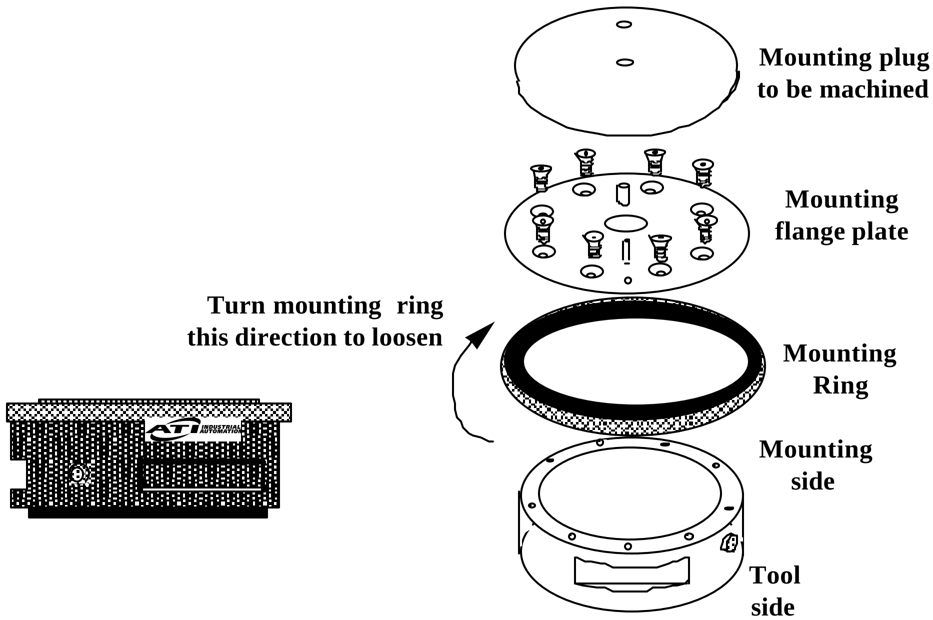


Figure 2.2 Using the mounting ring-plug adaptor

> ***Aside...***
>
> How the ring/plug adaptor 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).

Transducer Mounting Method III, User-designed Interface

The transducer can be mounted using the bolt pattern provided; see *Appendix B, Mechanical Layout.*

> ***Warning...***
>
> Do not attempt to drill, tap, machine, or otherwise modify the transducer. This could damage the transducer and will void the warranty. Do not attempt to remove any part of Nano, Mini or Omega model transducers as damage will occur.

2.4 MOUNTING YOUR TOOL

There are two methods for mounting your tool to most F/T transducers. Method II can only be used for the Gamma and Delta transducers. The two methods are described below:

Tool Mounting Method I, Standard Tool Adaptor

The tool adaptor is factory installed and the bolt circle is shown in *Appendix B, Mechanical Layout.* Most F/T tool adaptors follow the ISO 9409-1 mounting pattern. Machine your tool interface plate to attach to this bolt circle.

Tool Mounting Method II, Optional Tool Ring-plug Adaptor

- This method is similar to the optional mounting ring-plug adaptor. See *Section 2.3, MOUNTING THE TRANSDUCER, Method II, Optional Mounting Ring-plug Adaptor* 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 *Appendix B, Mechanical Layout* [see 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 2.3 for how the ring-plug adaptor works. The tool flange is not attached to the standard tool adaptor, but replaces it.

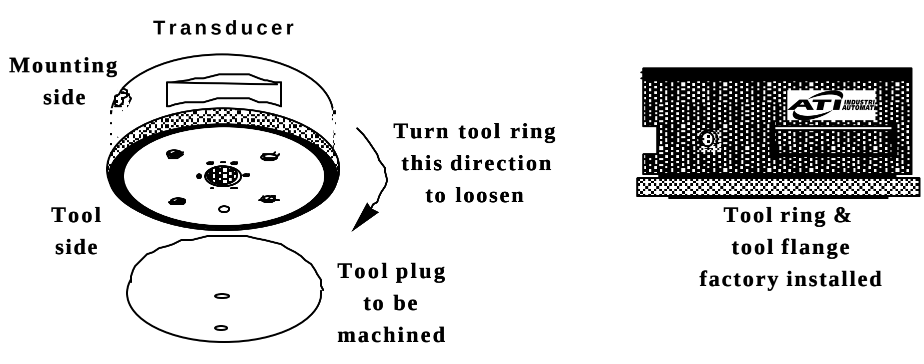


Figure 2.3 Using the tool ring-plug adaptor

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

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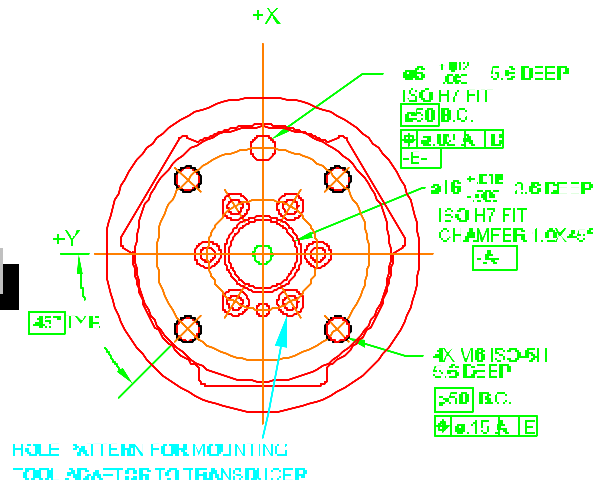
3

How It Works



Section **Page**

3.1 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 graphical representation of the electronics is presented in Section 3.2. A controlling software flow chart is shown in Section 3.3. A mechanical description is shown in Section 3.4.

3.2 ELECTRONIC HARDWARE

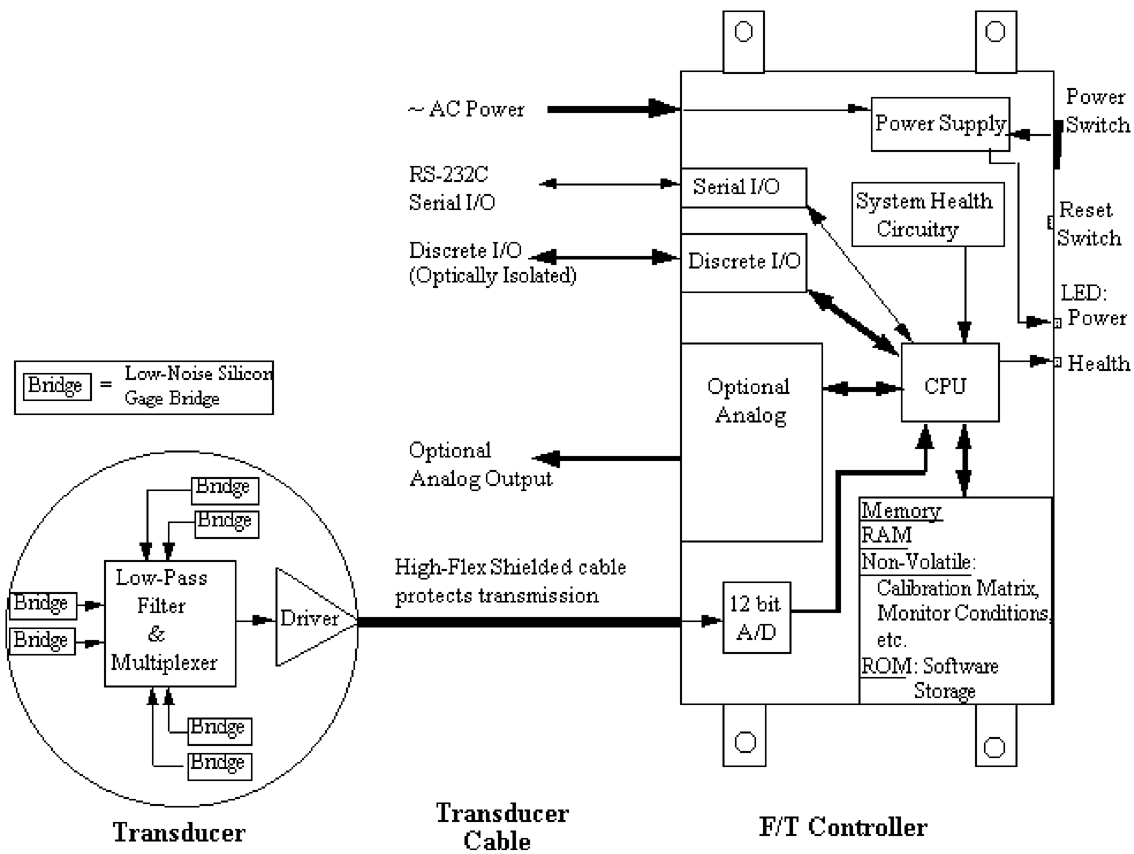


Figure 3.1 Electronic hardware outline

3.3 SOFTWARE OUTLINE

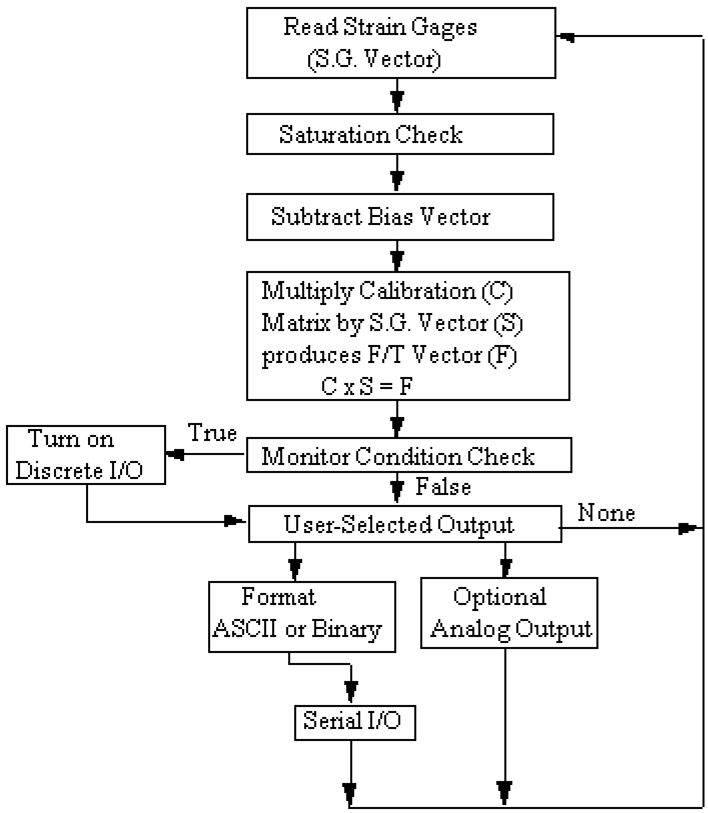


Figure 3.2 Controller flowchart

3.4 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.

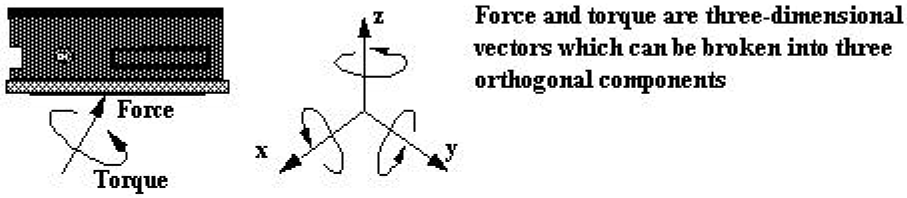


Figure 3.3 Applied force and torque vector on transducer

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

$$\sigma = E \cdot \varepsilon$$

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

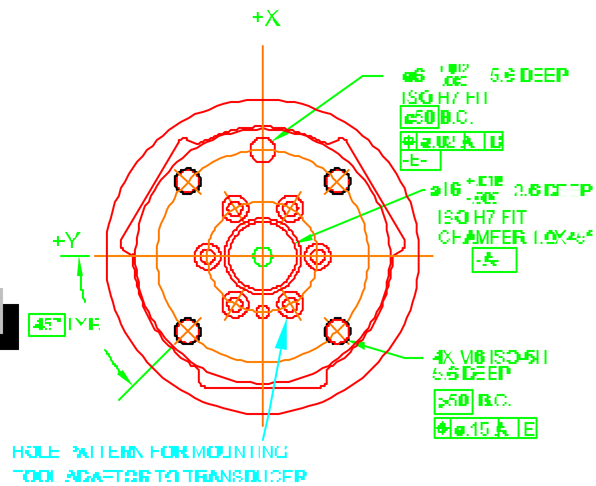
$$\Delta R = S_a \cdot R_o \cdot \varepsilon$$

ΔR = Change in resistance of strain gage
S_a = Gage factor of strain gage
R_o = Resistance of strain gage unstrained
ε = Strain applied to strain gage

The electronic hardware, described in *Section 3.2,* measures the change in resistance and the software, described in *Section 3.3*, converts this change to force and torque components.

4

Commands



4.1 COMMAND OVERVIEW AND PROTOCOL

The majority of commands consist of one to three ASCII characters. All commands can be in either upper or lower-case. Power-up or reset returns the F/T system to the default settings. Table 4.1 gives a brief review of all commands described in this manual. Table 4.2 reviews the nomenclature used in Table 4.1 and throughout this section.

COMMUNICATION SETUP COMMANDS	
Communication Data Mode	
CD A	Setup communication for ASCII output mode (Default).
CD B	Setup communication for Binary output mode.
Communication Checksum	
CD E	Enable a checksum at the end of binary communication.
CD U	Unable sending checksum at end of binary communication (Default).
Communication Data Type	
CD D	Setup communication for Decimal strain gage data output.
CD H	Setup communication for Hexadecimal strain gage data output.
CD R	Setup communication for Resolved force data output (Default).
Other Communication Setup Commands	
CA *b*	Communicate Analog: enabled (*b*=1) or disabled (*b*=0; Default).
CF *d*	Communicate Fast: level 1, 2 or 3 or disabled (*d*=0; Default). Speeds up output.
CL *b*	Enable Linefeed `<LF>` with `<CR>` (*b*=1; Default) or disable `<LF>` output (*b*=0).
CV *h*	Selects components of F/T values to be transmitted (Fx, Fy, Fz, Tx, Ty, Tz).

QUERY DATA REQUESTS	
Query F/T and Strain Gage Data	
QR	Query output of one Record of data in pre-selected communication setup.
^T	Speeds up data output by minimizing handshaking; similar to QR.
QS	Query output of a Stream of data in pre-selected type and mode.
Other Query Commands	
QC	Query the Calibration matrix in hexadecimal format. Used for error checking.
QP	Query Peaks: show the maximum and minimum F/T values collected (see SP).

SENSOR COMMANDS	
Sensor Bias	
SB	Performs a Sensor Bias. Stores bias reading in a 3 level buffer.
SU	Performs a Sensor Unbias. Removes last bias command from buffer.
SZ	Removes all previously stored biases from buffer.

Table 4.1 Command overview (continued on next page)

Optional Sensor Temperature Compensation	
ST *b*	Optional temperature compensation: enabled (*b*=1) or disabled (*b*=0; Default).

Sensor Peaks (see QP command)	
SP *b*	Collects the max. and min. F/T values: start (*b*=1) or stop (*b*=0; Default).
SC	Clear max. and min. F/T values by loading 9999 & -9999 in min. & max.
Other Sensor Commands	
SM *b*	Sensor Monitoring: disables (*b*=0) error message due to sensor error (saturation, disconnected transducer etc.) or enables error message (*b*=1; Default).
SF *d*	Sensor sampling Frequency allows optimizing for faster output when using CF.
SA *d*	Performs a moving average of *d* sensor data samples (*d*=0; Default).

I/O VERIFICATION	
ID	Reads and displays the state of all discrete input lines.
OD *h*	Sets the state of all discrete outputs as specified by hexadecimal number *h*.

FORCE MONITOR COMMANDS	
MC *s*	Creates a force Monitor statement *s*.
MD *d*	Deletes a force Monitor statement *d*.
ML	List all stored Force Monitor statements.

TOOL FRAME COMMANDS	
TF *d*	Selects a calibration matrix from tool frame list (*d*=0, 1, 2 or 3).
TL	List available tool frames.
TD *d*	Delete tool frame (*d*=1, 2 or 3).
TC *d,s,x, y,z,µ,ß,ø*	Constructs a new tool frame by changing the coordinate system (*d*=0..3; *s*=name; *x*, *y*, and *z* = translation; *µ*, *ß*, and *ø* = rotation).

MISCELLANEOUS COMMANDS	
^W	Warm start. Performs a system reset and is identical to pressing the reset button.
FC *d*	Sets the Filter Clock output (for Analog option).
^Q, ^S	XON and XOFF.
ZC 0, "*s*"	Creates a buffer of commands, *s*, that are executed at system power-up or reset.
RS	Save values from run memory into permanent memory.
RL	Reload values from permanent memory into run memory.

Table 4.1 Command overview (continued from previous page)

Format	Decimal ASCII code	Description
<CR>	13	**C**arriage **R**eturn
<LF>	10	**L**ine **F**eed
<SP>	32	**SP**ace
<ACK>	6	**ACK**nowledge
<NAK>	21	**N**egative **A**c**K**nowledgement
<error>	—	Error flag, 0, 1, 2 or 3 see *Section 4.2*
d	—	Represents decimal number
h	—	Represents hexadecimal digit (0 to F)
b	—	Represents binary digit (0 or 1)
s	—	Represents an alphanumeric string
a	—	Represents an alphabetic character
^	—	control character prefix

Table 4.2 Nomenclature table

When a command is received the F/T controller will respond with an **<ACK>** (decimal 6) control character if the command is valid or a **<NAK>** (decimal 21) control character if the command is not valid. If a **<NAK>** is sent then an error message follows with two **<CR><LF>**'s and the system prompt ">". If a valid command results in data being transmitted by the controller, the data is sent next. An **<ACK><CR><LF>**">" (system prompt) is sent showing that the command is complete. *The control characters are normally **not** visible on a standard RS-232 terminal.* Transmission of the **<LF>** may be suppressed by using the CL command described at the end of *Section 4.2*.

Characters sent by the serial port are echoed back. Commands sent to the F/T system must be terminated by a **<CR>**. A **<LF>** should not be sent.

Example — valid command:

user: `CD D`**<CR>**

response: `CD D`**<CR><LF>**

<ACK><ACK><CR><LF> (First **<ACK>** says command is valid and second **<ACK>** says the command has been implemented)

`>`

Example — invalid command:

user: `XYZ`**<CR>**

response: `XYZ`**<CR><LF>**

<NAK>`E114 Illegal command`**<CR><LF>**

<CR><LF>

`>`

4.2 COMMUNICATION SETUP COMMANDS

The F/T controller outputs three types of data through the RS-232 serial port: raw strain gage data in hexadecimal format, raw strain gage data in decimal integer format, and resolved force/torque data in decimal integer unit format. Data is available in either ASCII or binary format output mode. The length (in bytes) of an output record depends upon the type of data and the output mode. One "record" of data refers to a single set of strain gage readings or the resolved forces/torques. Also, "SG0" represents strain gage bridge 0, "SG1" represents strain gage bridge 1, etc. "Low" and "high" refer to low and high bytes of data.

Resolved force/torque data is transmitted in decimal integer unit format. The value of one unit force or one unit torque varies depending upon the model and the calibration, see command CD R for further information.

The Communication Data (CD) commands control the output data mode and type. The default at power-up or reset is ASCII output format and resolved force data output type. The mode or type of data may be changed by issuing the appropriate command. The new mode or type remains in effect until a different mode or type is selected or the system is reset.

Sensor Error

In the following command descriptions <*error*> represents the sensor error flag set by the F/T controller. The <*error*> flag can be a 0, 1, 2 or 3. The flag is normally 0 and is set to 1 if the forces on the system exceed the range **(saturation)**. A flag value of 2 indicates that a **transducer error** has occurred such as a broken gage or disconnected transducer cable. A value of 3 indicates that saturation and transducer error have occurred simultaneously. When a sensor error occurs the following will occur:

a) The health output line on the discrete I/O is turned off.
b) The error LED on the controller front is turned on.
c) Unless disabled the data output through the serial port produces an error message that will continue to repeat until the saturation and/or transducer error is stopped or the command "SM 0" is issued.
d) The error flag, <*error*>, is set to 1, 2 or 3.

The <*error*> flag is transmitted as an ASCII character or as a binary byte depending on the data mode selected.

Communication Data Mode (CD A, CD B)

Output can be in ASCII mode or binary mode. ASCII mode has the benefit of providing data in readable characters, but has a slower output rate due to the larger number of bytes in each record. Binary output has the benefit of faster output due to the smaller number of bytes needed to carry information, but cannot be read without further computation. The following commands select the data mode:

- **CD A** Communicate Data ASCII

  Selects ASCII output mode; default. All data transmitted in response to data query commands will be in ASCII format. XON/XOFF software handshaking is supported.

  CD A command format:

  user: `CD A<CR>`

  response:
  ```
  CD A<CR><LF>
  <ACK><ACK><CR><LF>
  >
  ```

- **CD B** Communicate Data Binary

  Selects binary output mode. All data transmitted in response to data query commands will be in binary format. XON/XOFF software handshaking is *not* supported.

  CD B command format:

  user: `CD B<CR>`

  response:
  ```
  CD B<CR><LF>
  <ACK><ACK><CR><LF>
  >
  ```

> ***Important...***
>
> When the controller is in binary mode (CD B), all numerical output will be in binary. This includes not only output data, but error messages as well. In ASCII mode (CD A), all numeric output will be readable.

Communication Data Checksum (CD E, CD U)

You can append a checksum to the end of force/torque data or strain gage data being sent in binary mode (see commands CD B, CD D, CD H, and CD R). A checksum will allow you to check the data for transmission errors. Appending the checksum will slow data transmission slightly.

- **CD E** Communicate Data checksum Enabled

  Appends checksum to end of strain gage or F/T binary record. The checksum is eight bits for serial output. The checksum is calculated by adding each value being sent, including the error byte (which is zero when no saturation or error is present), and dropping the most significant byte for the serial output; see the example below. The ASCII decimal data for the example is 1, 102, 14, 7723, 106, -158, -5138 where the error flag shows that the sensor is saturated. The prefix "0x" indicates a hexadecimal number. Serial output are converted to most and least significant bytes as follows:

  7723 = 0x1E2B where 0x1E = 30 & 0x2B = 43

  106 = 0x006A where 0x00 = 0 & 0x6A =106

  -158 = 0xFF62 where 0xFF = 255 & 0x62 = 98

Serial F/T binary output: <1><0><102><0><14><30><43><0><106><255><98><235><238>**<98>**
1+0+102+0+14+30+43+0+106+255+98+235+238 = 1122 = 0x0462
drop the most significant byte leaving $62_{16} = \mathbf{98}_{10}$

- **CD U** Communicate Data checksum Disabled (Un-enable)
  Stop sending the checksum. This command is the default.

Communicate Data Type (CD D, CD H, CD R)

Strain gage data or resolved force data can be selected for output. The following commands select the type of output:

- **CD D** Communicate Data Decimal gage
  Selects raw decimal strain gage data for output. Six strain gage readings are output each having a value from -2048 to 2047. In some special cases the sensor has eight strain gage readings. The examples are given for six gages.

  CD D command format:
  user: `CD D`**`<CR>`**
  response: `CD D`**`<CR><LF>`**
  `<ACK><ACK><CR><LF>`
  `>`

  In ASCII mode one data record consists of 45 bytes **for six strain gages** with linefeeds enabled. The first byte is the error flag followed by a comma and the strain gage data which is right-justified in six fields of six bytes each, separated by commas. The final bytes are **`<CR><LF>`**. The **`<LF>`** is not transmitted if it has been disabled by the CL command.

  In binary mode each record consists of 13 bytes **for six strain gages** and the checksum turned off (see CD U and CD E commands). The first byte is the error flag, followed by the six strain gage data values, which consist of two bytes with the high byte transmitted first.

  Data format of one raw strain gage record in ASCII and binary mode:

  ASCII: *`<error>,XXXXXX,XXXXXX,XXXXXX,XXXXXX,XXXXXX,XXXXXX`***`<CR><LF>`**
  SG0 SG1 SG2 SG3 SG4 SG5

  Binary: *`<error><SG0 high><SG0 low><SG1 high><SG1 low><SG2 high>`*
  `<SG2 low><SG3 high><SG3 low><SG4 high><SG4 low><SG5 high>`
  `<SG5 low>`

- **CD H** Communicate Data Hex gage
  Selects raw hexadecimal strain gage data for output. Six strain gage readings are output. In some special cases the sensor may output eight strain gage readings.

  CD H command format:
  user: `CD H`**`<CR>`**
  response: `CD H`**`<CR><LF>`**
  `<ACK><ACK><CR><LF>`
  `>`

Data format is similar to that of CD D except there on four bytes for each field instead of six.

> ***Aside...***
>
> For some special systems (non-standard) the transducer has eight strain gages. If your transducer has eight strain gages adjust the examples for the extra two gages.

- **CD R** Communicate Data Resolved

  Selects resolved force data for output; default. Force/torque output is in counts. Each count measurement value is shown in *Appendix A, F/T Specifications*.

  CD R command format:

  user: `CD R<CR>`

  response: `CD R<CR><LF>`
  `<ACK><ACK><CR><LF>`
  `>`

> ***Aside...***
>
> Force and torque values are reported in *counts*. Counts are integers values set so one count is set near the ideal resolution of the F/T system. The use of integers, instead of real numbers, produces faster output. For example, a US-30-100 sensor has 40 counts per pound. A force output of 128 counts would indicate a load of 3.20 pounds.
>
> 3.20 pounds = 128 counts ÷ 40 counts/pound.

In ASCII mode one data record consists of 45 bytes **if the output consists of six force/torque components; see CV *h* command**. The first byte is the error flag followed by a comma and the force/torque data in the order of Fx, Fy, Fz, Tx, Ty, Tz. The final bytes are **<CR><LF>**. The **<LF>** is not transmitted if transmission has been disabled using the CL command.

In binary mode each record consists of 13 bytes **if the output consists of six force/torque components; see CV *h* command**. The first byte is the error flag, followed by the six force/torque data values. Each value is two bytes with the high byte transmitted first.

Data format of one resolved force record in ASCII and binary mode:

ASCII: *<error>,XXXXXX,XXXXXX,XXXXXX,XXXXXX,XXXXXX,XXXXXX*<CR><LF>
Fx Fy Fz Tx Ty Tz

Binary: *<error><Fx high><Fx low><Fy high><Fy low><Fz high><Fz low>*
<Tx high><Tx low><Ty high><Ty low><Tz high><Tz low>

Communication Output Selection (CA *b*)

- **CA *b*** Communicate Analog

Enables or disables the sending of force/torque or gage data to the analog port. The analog port is optional. The analog port can output data together with the serial port. When the analog port is disabled invalid data is sent.

b = 0 stops sending updated force/torque or gage data to the analog port; default.

b = 1 enable current force/torque data to be sent to the analog port.

CA *b* command format:

user: `CA 1<CR>`

response:
```
CA 1<CR><LF>
<ACK><ACK><CR><LF>
>
```

If a value for b *is omitted the system will indicate the current state of the analog output port.*

CA command format:

user: `CA<CR>`

response:
```
CA<CR><LF>
<ACK>Analog outputs enabled<CR><LF>
<ACK><CR><LF>
>
```

Other Communication Setup Commands (CF *d*, CL *b*, CV *h*)

- **CF *d*** Communicate Fast

Streamlines processing of output data. Disabled by default. When CF is enabled communication data rates increase. The increase is accomplished by temporarily disabling certain software functions. The software is disabled in three levels as shown:

d=0: Level 0. CF command is disabled and the software commands shown below are restored to their normal state.

d=1: Level 1. Monitor conditions and sensor averaging (SA command) are disabled.

d=2: Level 2. Sensor Biasing is disabled. If the system is currently biased then the system will revert to the original resolved force/torque output (unbiased). Level 1 is included in this level.

d=3: Level 3. Saturation monitoring is disabled. If saturation occurs with this level enabled then no indication of saturation will occur. The error flag will **not** change from 0 to 1; however, the transducer error checking is still active (e.g. disconnected transducer cable) and will cause the error flag to change from 0 to 2. Level 1 and 2 are included in this level.

CF *d* command format:

user: `CF 1<CR>`

response:
```
CF 1<CR><LF>
<ACK><ACK><CR><LF>
>
```

If a value for d *is omitted the system will indicate the current state of the CF command.*

CF command format:

user: `CF<CR>`

response: `CF<CR><LF>`
`<ACK>Fast mode 1 enabled<CR><LF>`
`<ACK><CR><LF>`
`>`

- **CL *b*** Communicate Linefeed

  Enables or disables transmission of a linefeed, **<LF>**, character following every carriage return, **<CR>**, transmitted by the controller. Some serial devices output a **<LF>** for each **<CR>** received and it is suggested that the **<LF>** from the F/T controller be disabled to prevent two **<LF>** from appearing on the screen.

  b = 0 disable linefeed transmission
  b = 1 enable linefeed transmission; default

  CL *b* command format:
  user: `CL 1<CR>`
  response: `CL 1<CR><LF>`
  `<ACK><ACK><CR><LF>` (Line feed is now enabled)
  `>`

  If a value for b *is omitted the system will indicate the current value of* b.

  CL command format:
  user: `CL<CR>`
  response: `CL<CR><LF>`
  `<ACK>Line feed enabled<CR><LF>`
  `<ACK><CR><LF>`
  `>`

- **CV *h*** Communicate Vector

  This command selects force/torque components for transmission, allowing you to simplify or speed up processing. The value *h* is a hexadecimal number where each bit represents a force or torque component. The value of *h* is determined as follows:

(bits):	5	4	3	2	1	0
Component enabled:	Tz	Ty	Tx	Fz	Fy	Fx

Example:

`CV 14<CR>` (Enables Ty and Fz)
14 hex = 00010100 binary (The 1 in the third and fifth position represent Fz and Ty)

Attempting to enable a nonexistent component (with a system having fewer than 6 components) will generate an error. The system defaults to the factory settings.

CV *h* command format:
user: `CV 14<CR>`
response: `CV 14<CR><LF>`
`<ACK><ACK><CR><LF>` (Enables only Ty and Fz)
`>`

If a value for h *is omitted the system will indicate the current value of* h.

CV command format:
user: `CV<CR>`

response: CV**<CR><LF>**
<ACK>14**<CR><LF>**
<ACK><CR><LF>
>

4.3 QUERY COMMANDS

Query Data Request Commands (QR, ^T, QS)

- **QR** Query data Record
  Request output of one record of data in the preselected type and mode. See *Section 4.3 Communication Setup Commands*.
  QR command format:

  user: QR**<CR>**
  response: **<ACK>**<*record*>**<CR><LF>** (<record> depends on communication setup; see *Section* > *4.2*)
  <ACK><CR><LF>

- **^T** Query data record
  Same as QR except only the record is echoed back. Used for fast data output.
  ^T command format:

  user: **^T**
  response: <*record*>

- **QS** Query record Stream
  Request output of a stream of data records in the preselected type and mode. See *Section 4.2 Communication Setup Commands*. The stream may be interrupted by issuing any command or a **<CR>**.
  Output Format:

  user: QS**<CR>**
  response: **<ACK>**<*record 1*>
  < *record 2*>
  ...
  < *record n*>
  user: **<CR>** (any input stops output)
  response: **<ACK><CR><LF>**
  > (system prompt due to QS being terminated)
  <CR><LF>
  > (system prompt due to **<CR>** typed in by user)

System and user communications	Comments
`>CD A`	*Select ASCII output*
`>CD R`	*Select resolved force output*
`>QR`	*Request a single record*
`0,    89,     34,     76,    -23,     98,    -78`	*ASCII resolved force output*
`>CD D`	*Select raw strain gage values*
`>QR`	*Request a single record*
`0,    12,     56,   1000,    345,      0,   -678`	*ASCII strain gage records*
`>CD R`	*Select resolved force output*
`>QR`	*Request a single record*
`0,    89,     34,     76,    -23,     98,    -78`	*ASCII resolved force output*
`0,    89,     34,     76,    -23,     98,    -78`	*(user enters* **<CR>** *to halt output)*
`>`	*System halts output, processes* **<CR>**
`>`	

Figure 4.2 Communication setup and query examples

Query Calibration Matrix (QC)

- **QC** Query Calibration matrix

Request output of the calibration matrix for the current tool frame. *Appendix C* shows the calibration matrix that was loaded in your F/T controller at the factory. In the rare case that the calibration matrix has been corrupted this command allows you to check your current matrix against the one installed at the factory. This command outputs a calibration matrix record.

> ***Aside...***
>
> When using the QC command to view your default calibration matrix, be sure that tool frame 0 is selected. See the TF (Tool Frame) command for details on selecting tool frames.

QC command format:

user:	`QC<CR>`	
response:	`<ACK><Calibration Matrix Record>` `<ACK><CR><LF>`	(See below)
	`>`	(system prompt)

Calibration matrix record format example where *xxxx* represents the memory location and the numbers represent hexadecimal calibration values (see *Appendix C* for your actual matrix):

```
XXXX: 11111111 22222222 33333333 44444444 55555555 66666666 77777777
88888888<CR><LF>
XXXX: 11111111 22222222 33333333 44444444 55555555 66666666 77777777
88888888<CR><LF>
XXXX: 11111111 22222222 33333333 44444444 55555555 66666666 77777777
88888888<CR><LF>
XXXX: 11111111 22222222 33333333 44444444 55555555 66666666 77777777
88888888<CR><LF>
```

Query F/T Peaks (QP)

- **QP** Query Peaks

  Request output of maximum and minimum values of resolved force/torque data collected from SP command. The maximum values are preloaded with -9999 and the minimum values are preloaded with 9999. These preloaded values will be seen if the SP command was never enabled, after a hardware or software reset or after the SC command was issued. The QP command will not affect the collection of the maximum or minimum values while the SP command is enabled.

  QP command format:

  user: `QP`**<CR>**

  response: **<ACK>**<F_x*max*>, <F_y*max*>, <F_z*max*>, <T_x*max*>, <T_y*max*>, <T_z*max*>**<CR><LF>**
  <F_x*min*>, <F_y*min*>, <F_z*min*>, <T_x*min*>, <T_y*min*>, <T_z*min*>**<CR><LF>**
  <ACK><CR><LF>
  >

4.4 SENSOR COMMANDS

Sensor Biasing (SB, SU, SZ)

The F/T controller has the capability of storing three different bias (zero) readings. Biasing is useful for eliminating the effects of gravity (tool weight) or other forces acting on the end-effector. When a sensor bias is performed, the controller will read the forces and torques currently acting on the sensor and use these readings as a reference for future readings. Future readings will have this reference subtracted from them before they are transmitted.

> ***Aside...***
>
> When biasing ensure the force and torque readings are steady-state. Biasing while the transducer is vibrating, accelerating, or decelerating can provide a poor reference for your application.

- **SB** Sensor Bias

  Performs a sensor bias. Bias readings are stored in a LIFO (last-in-first-out) buffer. If an SB command is issued, the present bias reading (if any) is stored in the buffer. If an SU (Sensor Unbias) command is then issued, the previous bias reading is removed from the buffer and used as the current bias reading. Up to three levels of bias readings may be stored in this manner.

  If an SB command is issued when the bias buffer is full, the bias replaces the most recent bias. This leaves the first two biases undisturbed.

SB command format:

user: SB**<CR>**

response: SB**<CR><LF>**
<ACK><ACK><CR><LF>
>

- **SU** Sensor Unbias

  Removes the last bias from the LIFO buffer and the previous bias, if any, is used as the current bias reading.

  SU command format:

  user: SU**<CR>**

  response: SU**<CR><LF>**
  <ACK><ACK><CR><LF>
  >

- **SZ** Sensor Zero bias

  Removes all previously stored biases. This command is executed on power-up or reset.

  SZ command format:

  user: SZ**<CR>**

  response: SZ**<CR><LF>**
  <ACK><ACK><CR><LF>
  >

Optional Sensor Temperature Compensation (ST *b*)

Strain gage output can shift with change in temperature. This shift is in the form of a bias shift and a gain shift.

Bias shift is the case where a change in temperature causes the output to change or shift by ±X; where X is a function of temperature. The bias shift is normally small since the strain gages are in a bridge that cancels most of the bias shift, but the bias shift may be more apparent on high resolution sensors. You can eliminate the bias shift by performing a software sensor bias before measuring your load. An example of a bias shift: You bias the sensor and the F/T output should be reading near zero. The temperature shifts 10°F and the F/T output shows a 10 count reading in the Fz direction even though the load and orientation have not changed. This error is described as a percentage of full scale; in this case, it would equal 10 counts divided by the rated load (in counts).

> ***Aside...***
>
> Bias shift can also occur from any change in induced strain of the outer wall of the transducer, such as a change in interface plate screw tension.

Gain shift is the temperature-induced shift in force and torque output by Y% of the reading. An example of gain shift with no compensation: You bias the sensor and place a 500 count load in Fz which reads 500 counts. You take the load off. The temperature shifts 10°F and you bias the sensor—which takes out the bias shift—and reapply the 500 count load. The output changes to 507 counts, which is a change of (507-500)÷500 × 100% = 1.4% per 10°F. A temperature compensation method is available to correct for the gain shift.

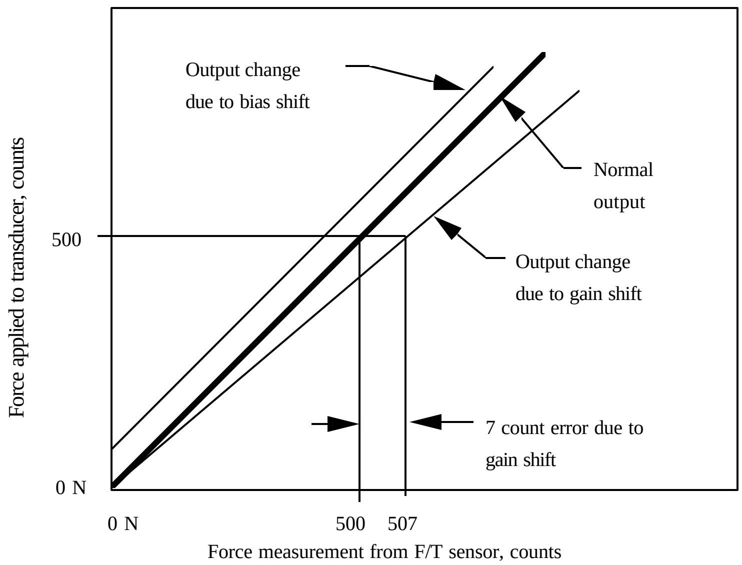


Figure 4.3 Example of how F/T output is effected by temperature changes

Figure 4.3 shows an example of how bias and gain shift affect the output of the F/T sensor. Bias shift changes the starting point, but not the slope. When you perform a software sensor bias you bring the starting point back to zero eliminating the bias shift. Gain shift changes the slope of the output. Temperature compensation will correct this gain shift. The gain shift error can be corrected in the range of 0°C to 70°C.

Transducer operate at a temperature slightly higher than ambient due to self-heating of the strain gages. This usually poses no problem since after the sensor is warmed up—around 5 to 30 minutes—the sensor can be biased to remove any bias shift due to this self-heating. A problem may occur if additional mass that you want to measure is being placed directly against the sensor since this would change the temperature of the sensor causing bias shift. High-resolution Nano and Mini sensors have the most bias shift due to additional mass being placed directly against them. You can prevent this bias shift by thermally insulating the transducer from the mass—i.e. providing a ceramic or plastic plate between the load and the transducer. When the transducer is mounted on a metal object, i.e. a robot arm, and a metal tool is mounted to the tool adaptor then the addition of a mass has little or no effect on the temperature of the sensor.

Note: with optional temperature compensation enabled(ST 1), it is possible to have strain gage values reported outside of the -2048..2047 range.

- **ST *b*** Sensor Temperature compensation (Optional)
  b=0: disable temperature compensation of force/torque and gage data; default.
  b=1: enable temperature compensation of force/torque and gage data.
  The bias and gain shift are compensated as shown in the above paragraph. Performing the SB (Sensor Bias) command as close as possible to the temperature at which you will be measuring force/torque output will reduce bias shift and produce the most accurate output.

  ST *b* command format:

  user: `ST 1<CR>`
  response:
  ```
  ST 1<CR><LF>
  <ACK><ACK><CR><LF>
  >
  ```

  The current state of sensor temperature compensation will be indicated when the value b *is omitted.*

  ST command format:

  user: `ST<CR>`
  response:
  ```
  ST<CR><LF>
  <ACK>Temperature compensation enabled<CR><LF>
  <ACK><CR><LF>
  >
  ```

Sensor Peaks (SP *b*, SC)

The two commands below work with the QP (Query Peaks) command to collect and clear the maximum and minimum F/T values.

- **SP *b*** Sensor Peaks
  b=1: Enable collection of force/torque maximum and minimum values.
  b=0: Disable collection of force/torque maximum and minimum values; default.
  When enabled maximum and minimum F/T values are collected until reset or the command is disabled. The maximum and minimum values collected are kept in a buffer until they are cleared by the SC command or a system reset occurs. Use the QP command to read the values stored in this buffer. You can examine this buffer with SP enabled or disabled.

  SP 1 command format:

  user: `SP 1<CR>`
  response:
  ```
  SP 1<CR><LF>
  <ACK><ACK><CR><LF>
  >
  ```

  The current state of SP command will be transmitted when the value b *is omitted.*

  SP command format:

  user: `SP<CR>`
  response: `SP<CR><LF>`

```
<ACK>Peak monitoring enabled<CR><LF>
<ACK><CR><LF>
>
```

- **SC** Sensor peaks Cleared

  Loads -9999 in the maximum values and 9999 in the minimum values. This command is executed on system reset. If the sensor peak monitoring is enabled and the SC command is issued then the buffer will be cleared and new minimum and maximum values will be collected (issuing the SC command does **not** disable peak monitoring).

  SC command format:

  user: `SC<CR>`

  response:
  ```
  SC<CR><LF>
  <ACK><ACK><CR><LF>
  >
  ```

Sensor Error Message (SM *b*)

- **SM *b*** Sensor Monitoring

  b=1: Enable sending error message if sensor error is occurring; default.
  b=0: Disable sending error message if sensor error is occurring.
  The sensor monitoring command only affects the transmission of an error message being sent due to a sensor error. The error flag health line and health LED are not affected by this command; see *Section 4.2*. The sensor error could occur due to saturation, disconnected transducer cable or broken transducer. This command is enabled by default. When the CF 3 command is issued the sensor error due to saturation is disabled; see the CF command. While the SM command is enabled and a sensor error is occurring an error message will repeat continuously until the error is corrected or disabled.

  SM 0 command format:

  user: `SM 0<CR>`

  response:
  ```
  SM 0<CR><LF>
  <ACK><ACK><CR><LF>
  >
  ```

  If a value for b *is omitted the system will indicate the current state of the SM command.*

  SM command format:

  user: `SM<CR>`

  response:
  ```
  SM<CR><LF>
  <ACK>Sensor monitoring disabled<CR><LF>
  <ACK><CR><LF>
  >
  ```

Sensor Sampling Frequency (SF *d*)

- **SF *d*** Sensor sampling Frequency

  The sampling frequency sets the internal update rate of the controller and is set by the factory for six-axis output (CV 3F) with the CF command set at 0 (default). If you change the number of axis readings or use the CF command for faster output you will have to change the sampling frequency, *d*, to provide the optimum output speed. **You do not need to change the sampling frequency if you do not need a faster speed.** Use Table 6.1 to select the optimum sampling frequency value to use in the SF command.

SF *d* command format:

user: `SF 2818<CR>`
response: `SF 2818<CR><LF>` (Sampling frequency changed to 2818 Hz)
`<ACK><ACK><CR><LF>`
`>`

If a value for d *is omitted the system will indicate the current state of the SF command.*

SF command format:

user: `SF<CR>`
response: `SF<CR><LF>`
`<ACK>2818<CR><LF>`
`<ACK><CR><LF>`
`>`

Sensor Averaging (SA *d*)

- **SA *d*** Sensor Averaging

Performs a moving average of *d* samples of sensor data. This can be useful to reduce the effects of mechanical vibrations and inertia. The parameter *d* must be 0, 2, 4, 8, or 16. A value of 0 disables the averaging function and is the default. The CF 1 command also disables this feature.

SA *d* command format:

user: `SA 4<CR>`
response: `SA 4<CR><LF>`
`<ACK><ACK><CR><LF>`
`>`

If a value for d *is omitted the system will indicate the current state of the SM command.*

SA command format:

user: `SA<CR>`
response: `SA<CR><LF>`
`<ACK>Averaging filtering on Filter = 4<CR><LF>`
`<ACK><CR><LF>`
`>`

Aside...

A moving average is performed as follows:

1. Collect the number of records requested (2, 4, 8, or 16)
2. Calculate the mean value of the collected records
3. Output the calculated mean value
4. Remove the oldest value collected and replace it with a new value
5. Go to step 2 and continue

4.5 DISCRETE I/O COMMANDS

See *Section 5* for a complete description of the discrete I/O. The commands shown in this section are issued through the serial port and involve the use of the discrete I/O.

I/O Verification (ID, OD *h*)

The following commands are useful for verifying proper discrete I/O connection. See *Section 5* for pin-out and electrical specifications.

- **ID** Input Discrete
  Reads and displays the state of all discrete input lines. When the ID command is issued, seven characters representing the status of the input lines are transmitted.

  ID command format:

  user: `ID` **<CR>**

  response: `ID` **<CR><LF>**
  <ACK><I_3><I_2><I_1><I_0>**<sp>**<*M*><*B*>**<CR><LF>**
  <ACK><CR><LF>
  >

  <I_3> = Input bit 3, where 1 is on and 0 is off
  <I_2> = Input bit 2
  <I_1> = Input bit 1
  <I_0> = Input bit 0
  <*M*> = Monitor input
  <*B*> = Bias input

System and user communications	**Comments**
>ID	*Request discrete inputs*
0100 10	*Input bits 3, 1, and 0 are off*
	Monitor line is on, bias line is off
>	

Figure 4.4 Example of ID command

- **OD *h*** Output Discrete
  Sets the state of all discrete outputs and controller error LED as specified by the hexadecimal number *h* where the value of *h* is determined by:

bit	function
0	Discrete I/O Output bit 0
1	Discrete I/O Output bit 1
2	Discrete I/O Output bit 2
3	Discrete I/O Output bit 3
4	Discrete I/O Status line

5 Health LED on controller front
6 Discrete I/O health line

OD *h* command format:

user:	`OD 4A<CR>`	

response:	`OD 4A<CR><LF>`
	`<ACK><ACK><CR><LF>`
	`>`
		(4A = 01001010 binary which turns on discrete I/O output bit 1, 3 and the discrete I/O health line)

Sending the command with the parameter h *omitted is the same as sending "OD 0."*

> ***Aside...***
>
> If the discrete I/O health line is off (not conducting) an error is occurring. Example errors are blown fuse, gage saturation, disconnected transducer, powered-down system, etc.
> The health line is on (conducting) when there is no error.

> ⚠ ***Warning...***
>
> If the OD (Output Discrete) command is used to turn the off the health line be sure to turn it back on before using the health line to check for system errors.

Force Monitoring Commands (MC *s*, MD *d*, ML)

You can program the F/T controller to monitor force and torque thresholds. The thresholds are programmed in statements called monitor conditions, using the MC command, and stored in non-volatile memory. The MD and ML commands are used to delete and list out the stored monitor condition(s), respectively.

The discrete I/O is used to select the monitor condition(s) to be scanned and to output the programmed thresholds that have become valid, see *Section 5*.

The F/T controller can store a total of 32 monitor conditions.

> ⚠ ***Warning...***
>
> New monitor conditions and tool frames are stored in run-time memory, which is volatile. Run-time memory is reloaded from permanent memory after system reset or power up. Use the RS (Run Save) command to store any monitor condition or tool frame changes in permanent memory. **Changes will be lost if not stored in permanent memory.** Keep a written copy of monitor conditions and tool frames in case of accidental erasure or system failure.

- **MC *s*** Monitor Create
  Creates a monitor condition, *s*. The monitor condition consists of:

Input code/Threshold condition/Output code

Input and output codes consist of a four-bit binary code (e.g. 0101) and work with the input and output discrete I/O lines; see *Section 5.* Leading zeros are not required with the output or input codes (i.e. 0101 is the same as 101). The input code identifies the monitor condition for scanning. The output code is used to identify which monitor conditions became true during scanning.

The threshold is a statement consisting of three components:

a) Force or torque component: Fx, Fy, Fz, Tx, Ty, Tz.
b) Greater or less than sign: >, <
c) Threshold value in counts; see *Appendix A*.

A condition is considered true if the condition has been selected for scanning and the threshold condition is satisfied by the measured forces and torques.

MC *s* command format:

user: `MC 1001/FZ>123/0101`**<CR>**

response: `MC 1001/FZ>123/0101`**<CR><LF>**
<ACK><ACK><CR><LF>
`>`

where:

MC is the command name typed at the prompt.
1001 is the input code (send this code to the discrete I/O to turn this condition on).
FZ>123 is the threshold condition (if Fz is greater than 123 this statement is true).
0101 is the output code (sent to the discrete I/O if threshold condition is true).

As you can see, it is easy to use the monitor condition to look for a force or torque above or below a preset value. You can combine monitor conditions to check for a variety of complex conditions. An example follows:

Example: The force sensor is to check for Fz (force along the Z-axis) greater than 600 counts, but less than 800 counts. The following monitor conditions should be written to implement this:

```
MC 1101/FZ<800/1000
MC 1101/FZ>600/0001
```

The graph below shows the output code based on the value of Fz. You can determine when Fz is between 800 and 600 counts by sending an input code of 1101 and waiting for an output code of 1001. An output code of 1000 indicates that Fz is below the lower limit, while an output code of 0001 indicates that Fz is above the upper limit.

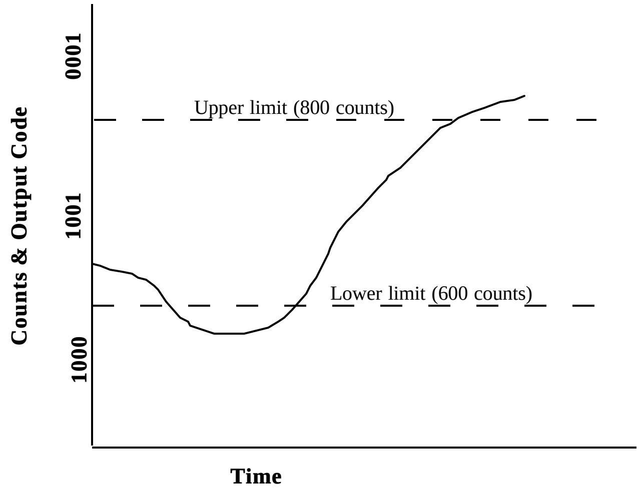


Figure 4.5 Correlation of output code vs. counts for the monitor condition example

After each monitor condition is created a statement number is assigned to it. You can view these statement numbers when using the ML command. If an invalid monitor condition is entered then an error is displayed and the monitor condition is not assigned a statement number. You must use the RS command to permanently store any changes to the monitor conditions.

Warning...

Do not forget to use the RS (Run Save) command to store new monitor conditions into permanent memory.

- **MD *d*** Monitor Delete

  Deletes monitor condition where *d* is the statement number 1–32. Use the ML command to find the statement number assigned to the monitor condition you wish to delete. MD * deletes *all* stored statements. If MD * is used then a confirmation statement is given to ensure that all monitor statements are to be deleted.

  MD *d* command format:

  user: `MD 3`**<CR>**

  response: `MD 3`**<CR><LF>** (deletes monitor condition # 3)
  <ACK><ACK><CR><LF>
  `>`

System and user communications	Comments
`>MC 0001/Fy>245/0101`	*First construction of a monitor condition*
`>mc 1/Fy>245/101`	*Second monitor condition. Statement is equivalent to first statement*
`>Mc 0111/Tx<789/1111`	*Third monitor condition. Note that commands are not case sensitive*
`>ML`	*List all monitor conditions*
`1) 0001/Fy>245/0101          2) 0001/Fy>245/0101`	
`3) 0111/Tx<789/1111`	
`>RS`	*Permanently save monitor conditions*
`>MD *`	*Delete all monitor conditions*
`Delete all monitor conditions (Y/N)? Y`	*Query confirming deletion of conditions*
`>ml`	*List all monitor conditions*
`E129 No monitor conditions(s)`	*Response when there are no conditions*
`>`	

Figure 4.6 Example of constructing, deleting, and listing monitor conditions

- **ML** Monitor List

  Lists all stored Monitor conditions (1 to 32), including their respective statement numbers. If no monitor conditions are stored then an error message is given informing that no monitor conditions exist.

  ML command format:

  user: `ML`**<CR>**

  response: `ML`**<CR><LF>**
  <ACK>1)<monitor condition>**<sp>..<sp>**2)<monitor condition>
  (the list continues until all the monitor conditions are shown)
  <ACK><CR><LF>
  `>`

4.6 TOOL FRAME COMMANDS

The default calibration matrix resolves forces and torque with respect to the transducer origin. By using a tool transformation it is possible to directly measure the forces and torques acting at some point other than the origin of the transducer. Tool transformations are particularly useful when this point is chosen as the point of contact between the robotic end-effector (tool) and the object it is working on. The tool transformation may also rotate the coordinate frame to align resolved force/torque components with the natural axes of the task geometry.

It is possible to have four calibration matrices stored in your F/T controller. The factory installs the original calibration matrix which represents the calibration with the X, Y and Z orientation shown on the transducer drawings in *Appendix B.* This factory calibration matrix is stored as tool frame #0. You can change this calibrated orientation (rotation or translation) by changing the calibration matrix with the TC command. It is possible to delete one of the tool frames by using the TD command. You must use the RS command to store any tool frame changes into permanent memory or they will be lost with a software or hardware reset.

> ***Aside...***
>
> Multiple transducers can be used with one controller. In some special cases more than one factory calibration matrix can be placed into one controller. With this capability one to four transducers can be used with one controller, although not simultaneously. This allows you to switch from one matrix to another with the TF (Tool Frame) command. Call ATI Industrial Automation for more information.

Tool Frame Selection, Listing and Deleting (TF *d*, TL, TD *d*)

- **TF *d*** Tool Frame selection

  Select a tool frame, in run memory, *d* = 0, 1, 2 or 3. The original calibration matrix is stored in position 0. If you want the tool frame selected to start up after software or hardware reset send an RS command after selecting the tool frame. Issuing the TF command with no other value returns the current state.

  TF *d* command format:

  user: `TF 1<CR>`

  response: `TF 1<CR><LF>`

  `<ACK><ACK><CR><LF>` (tool frame 1 selected)

  `>`

  If a value for d *is omitted the system will indicate the current state of the TF command.*

  TF command format:

  user: `TF<CR>`

response:
```
TF<CR><LF>
<ACK>1) TEST1 ,     0,    100,    0,    0,    0,
900<CR><LF>
<ACK><CR><LF>
>
```

Where the tool frame number, “1”, is displayed first, name of the tool frame second and the translational and rotational numbers last; see the TD command.

> ***Aside...***
>
> Whenever a new tool frame is selected any bias points will be changed. This can make the output data seem inaccurate if the output data is expected to be relative to a bias taken before the tool frame selection.

- **TL** Tool frame Listing

  List the four available tool frames. The listing consists of a six-character name and six integers representing rotational and translational codes that change the original calibration matrix.

  TL command format:

  user:
  ```
  TL<CR>
  ```
  response: (Example values shown)
  ```
  TL<CR><LF>
  <ACK>0) FT0000 ,      0,     0,     0,     0,     0,
  0<CR><LF>
  1) TEST1 ,      0, 100,     0,     0,     0, 900<CR><LF>
  2)              ,      0,     0,     0,     0,     0,
  0<CR><LF>
  3)              ,      0,     0,     0,     0,     0,
  0<CR><LF>
  <ACK><CR><LF>
  >
  ```

- **TD *d*** Tool frame Delete

  Delete a tool frame from run memory, *d* = 1, 2 or 3. Use the RS command to store running memory into permanent memory. You can also use *d* = * (asterisk character) to delete all tool frames except the calibration matrix stored in 0 tool frame. If you use the “TD *” then you will be asked “Delete all tool frames (Y/N)?” You cannot delete the 0 tool frame and you cannot delete the tool frame you are currently using.

  TD *d* command format:

  user:
  ```
  TD 1<CR>
  ```
  response: (delete tool frame 1)
  ```
  TD 1<CR><LF>
  <ACK><ACK><CR><LF>
  >
  ```

Tool Frame Construction (TC *d, s, x, y, z, µ, ß, ø*)

- **TC *d, s, x, y, z, µ, ß, ø*** Tool frame Construction

  This command allows you to shift and/or rotate the sensor reference frame by specifying offsets from the currently selected frame. The parameter *d* (1, 2 or 3) represents the tool frame location in which to store the newly-constructed calibration matrix (in run memory use RS command to store into permanent memory). You cannot store into tool frame position 0 since this holds the factory calibration and can only be changed at the factory. If you attempt to store a newly-constructed matrix in the tool frame position 0 you will receive an error message. You also cannot construct a new tool frame in the currently selected tool frame (i.e., if you want to construct a new calibration matrix for tool frame 1, your current tool frame cannot be 1, but should be 0, 2 or 3 if defined). The newly-constructed tool frame is built from the currently selected tool frame.

The string *s* is a one-to-six character name that is assigned to this tool frame.

The integers x, y, and z represent the translation distances along each of these axes. To derive values for these numbers, divide the actual distance by the Tool Transform Factor. The Tool Transform Factor for your sensor calibration can be found in Appendix A. For example, to translate a metric Nano17's coordinate system by 0.8 mm, the value would be (0.8 mm)/(0.05 mm/unit)=16 units.

The integers *μ*, *ß*, and *ø* represent 1/10 of a degree for rotation about X-, Y- and Z-axis respectively (e.g. if *ß* = 100 then the coordinate system is rotated 10° about the Y-axis). In a tool transformation, the order of the rotations matters. The X-rotation occurs first, followed by rotation about Y (in its new orientation), then Z. Therefore, you MUST express your rotations in this order. Use the right hand rule to find the positive and negative rotation. Example of right hand rule: point your thumb along the positive axis you are interested in rotating about and your fingers will roll about the positive rotation direction.

Suppose we want to move the origin of our Gamma sensor (US units) -1 inch in the X direction and 6 inches in the Z direction. We also want to rotate -90 degrees about the X-axis, then 5.3 degrees about the Z-axis. We will store this in tool frame 2 and name it STORE2.

TC *d, s, x, y, z, μ, ß, ø* command format:

User: `TC 2, STORE2, -100, 0, 600, -900, 0, 53<CR>`

response: `TC 2, STORE2, -100, 0, 600, -900, 0, 53<CR><LF>`
`<ACK><ACK><CR><LF>`
>

Warning...

Do not forget to use the RS (Run Save) command to store new tool frames into permanent memory.

4.7 OTHER F/T COMMANDS

Zip Macro Create Start-up Buffer (ZC 0, "*s*")

- **ZC 0, "*s*"** Zip macro Create

Creates a buffer of commands, *s*, which are sequentially executed at system power-up or reset. Commands must be separated by a semicolon, ";". The buffer is stored in permanent memory (you do not need to use the RS command).

ZC 0,"*s*" command format:

user: `ZC 0, "CD A; SA 4;SB"`**<CR>**

response: `ZC 0, "CD A; SA 4;SB"`**<CR><LF>**
<ACK><ACK><CR><LF>
>

If the ZC command is used without any parameters the start-up buffer is displayed.

ZC command format:

user: `ZC`**<CR>**

response: `ZC`**<CR><LF>**
<ACK>`CD A; SA 4;SB;`**<CR><LF>**
<ACK><CR><LF>
>

To clear the buffer simply enter an empty command string: ZC 0,""**<CR>**

Warm Start (^W)

- **^W (Control-W)** Warm start

Performs a system reset and is identical to pressing the reset button. A header message will appear on start-up which consist of:

1) Rated force and torque in force units (pounds, Newtons, etc.) and torque units (pound-inches, Newton-meters, etc.). Some special calibrations have different force and torque units.
2) Number of counts per force units and torque within parentheses.
3) Serial number (SN).
4) Force and torque vectors displayed. The hex value 3F represents that all six components of the F/T vector are displayed. See the CV command.
5) Software version.
6) Copyright notice.

Example Gamma transducer calibrated as a 15/50 with 15 lb rated force and 50 lb-in rated torque, 80 counts per pound and 80 counts per pound-inch, SN FT0000, all six components of the F/T vector and software version 4.25:

user enters: ^W

```
<CR><XON><LF>
<XON><CR><LF>
F15/T50(80/80)   SN FT0000-3F   Version 4.25<CR><LF>
Copyright(c) 1990, 1991, 1992 by Assurance Technologies, Inc., Garner,
NC<CR><LF>
All Rights Reserved<CR><LF>
>
```

Filter Clock (FC *d*)

- **FC *d*** Filter Clock

  Used in conjunction with the analog output filter to modify the update filter frequency. The value *d* can be between 0 and 255. Typing FC without the *d* will show the current value of FC. The default of FC is 81. The value of FC is not saved so after any reset the value of FC is changed back to the default 81. If you need to save the value of FC then add it to Zip macro described above.

  See *Section 6.3, ANALOG OUTPUT DESCRIPTION* and Table 6.4 for details on changing the analog output filter.

XON and XOFF (^Q, ^S)

Software handshaking (XON/XOFF) is implemented for all ASCII communications except binary communications.

- ^**Q** XON
- ^**S** XOFF

Upon power-up or system reset the F/T controller ignores any previously received XOFF and begins to transmit data. Also, the F/T controller transmits an XON to clear any previously transmitted XOFF so data can be received.

Store and Reload Run Memory (RS, RL)

There are two types of memory, run (or working) and permanent. After a reset permanent memory is loaded into run memory. If any changes are made in run memory those changes can be used immediately, but are temporary until the RS command saves those changes to permanent memory. If you do not like the changes you have made in run memory you can reload the permanent memory back into run memory with the RL command.

- **RS** Store Run memory into permanent memory

  The RS command will store any deletions or additions that were done in run memory (working memory) into permanent memory. If you do not perform an RS command after changing the tool frame and a software or hardware reset occurs the change will be lost.

  RS command format:

user:	`RS<CR>`	

response:	`RS<CR><LF>`
	`<ACK><ACK><CR><LF>`
	`>`
		(run memory stored into permanent memory)

- **RL** Load permanent memory into Run memory

  The RL command will take information (e.g. tool frames and monitor conditions) stored in permanent memory and place them into run memory. Any changes that were made in run memory and not stored with the RS command will be lost when an RL command is executed.

  RL command format:

user:	`RL<CR>`	
response:	`RL<CR><LF>` `<ACK><ACK><CR><LF>`	(permanent memory stored into run memory)

>

⚠ *Warning...*

New monitor conditions and tool frames are stored in run-time memory, which is volatile. Run-time memory is reloaded from permanent memory after system reset or power up. Use the RS (Run Save) command to store any monitor condition or tool frame changes in permanent memory. **Changes will be lost if not stored in permanent memory.** Keep a written copy of monitor conditions and tool frames in case of accidental erasure or system failure.

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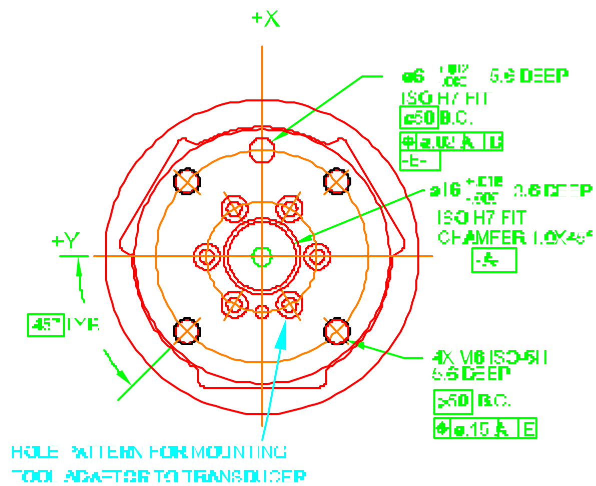
5

Serial and Discrete I/O



Section **Page**

5.1 SERIAL AND DISCRETE I/O PIN ASSIGNMENTS

Serial I/O Pin-out

The RS-232 serial port is a female 9 pin D-subminiature connector using a 3-wire communication.

Pin	Signal
1	N/C
2	Receive
3	Transmit
4	Reserved
5	Ground
6	N/C
7	N/C
8	N/C
9	N/C

N/C = Not Connected

Table 5.1 RS-232 serial I/O connector pin assignments

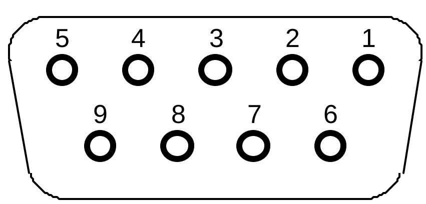


Figure 5.1 Serial I/O port as viewed from rear of F/T controller

Discrete I/O Pin-out

The Discrete I/O port is a male 25 pin D-subminiature connector.

PIN		SIGNAL	DESCRIPTION
1		+ Input bit 0	Input lines are read as a nybble indicating which monitor condition(s) should be scanned. The Input lines are only read when the Monitor line is toggled from low to high.
	14	- Input bit 0	
2		+ Input bit 1	
	15	- Input bit 1	
3		+ Input bit 2	
	16	- Input bit 2	
4		+ Input bit 3	
	17	- Input bit 3	
5		+ Output bit 0	Output lines represent a nybble, indicating which monitor condition(s) have been triggered. The Output lines are only valid when the Status line is high.
	18	- Output bit 0	
6		+ Output bit 1	
	19	- Output bit 1	
7		+ Output bit 2	
	20	- Output bit 2	
8		+ Output bit 3	
	21	- Output bit 3	
9		+ Monitor	Indicates that Input lines are set up and starts monitor condition scanning.
	22	- Monitor	
10		+ Status	Indicates that Output lines are set up and monitor condition(s) have been triggered.
	23	- Status	
11		+ Bias	When a rising edge (transition from low to high) occurs a bias command is executed.
	24	- Bias	
12		+ Health	Error line. Line is high normally and goes low if an error occurs. Works the opposite of Health LED.
	25	- Health	
13		Reserved	

Table 5.2 Discrete I/O connector pin assignments

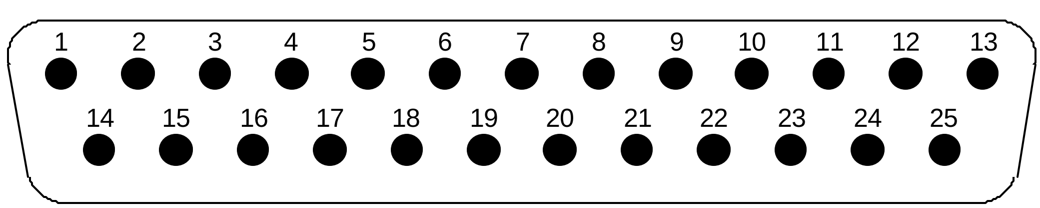


Figure 5.2 Discrete I/O port as viewed from rear of F/T Controller

5.2 SERIAL I/O DESCRIPTION

The Serial I/O port uses the RS-232 format with 8-bit transmission, no parity, one stop bit, and selectable baud rate (1200, 9600, 19200, 38400). See *Section 1, Getting Started*, for examples of serial port interfacing.

5.3 DISCRETE I/O DESCRIPTION

The Discrete I/O signals are optically isolated and require an external power supply. Output signals are internally protected by transient suppression diodes. Typical input and output connections are shown along with a timing diagram.

The Discrete I/O port has three major functions: monitor conditions, health line, and bias line. Each of these functions are described in this section.

Typical Input and Output Connections

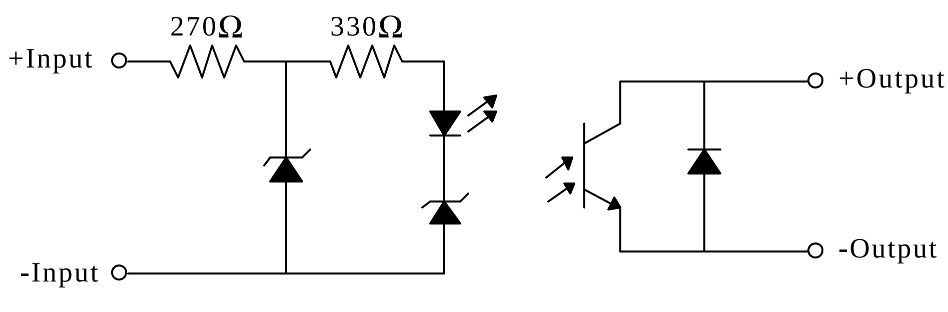


Figure 5.3 Discrete I/O Circuitry

Monitor Conditions

The discrete I/O works with the monitor conditions, described in *Section 4.5, Force Monitoring Commands (MC s, MD d, ML)*, to indicate force/torque thresholds, greatly simplifying your programming task. The user must handshake with the input, output, status, and monitor discrete I/O lines to use the monitor conditions.

The **input** lines allow you to select monitor conditions to be scanned.

The **output** lines indicate which monitor conditions have been triggered.

The **monitor** line instructs the F/T controller to scan the monitor conditions whose input code matches the Input lines.

The **status** line indicates that one or more monitor conditions have been triggered. When the status line is asserted, a valid output code is on the output lines.

To use the discrete I/O to scan for triggered monitor conditions do the following:

a) Enter monitor conditions using the software commands shown in *Section 4.6*.

b) Place the input code of the monitor condition(s) you would like to have scanned onto the input lines. See pin-out shown in Table 5.2.

c) Bring the monitor line low if it is high.

d) Wait for the status line to go low if it is high.

e) Bring the monitor line high to indicate a valid input code is present. The input lines are read after the rising edge of the monitor line is seen. See the timing diagram in Figure 5.4.

f) While the monitor line is high the selected monitor condition(s) are scanned for true conditions. If a true condition occurs then the output code of that monitor condition is presented to the output lines of the discrete I/O. If more than one output code is triggered then the F/T system outputs the logical OR of the triggered output codes.

   Example: Three output codes are triggered: 0010, 1000, 1100

$$\begin{array}{rr} & 0010 \\ & 1000 \\ \vee & \underline{1100} \\ & \mathbf{1110} \end{array}$$

   (“∨” is the mathematical symbol for logical OR.) The code 1110 is sent to the discrete output lines.

g) Once the output code is presented the system will assert the status line. **Monitor conditions are no longer scanned** as long as the status line is asserted.

h) The monitor line should be lowered after the output code is read.

i) When the F/T system detects the monitor line lowered, it will remove the output code from the discrete I/O port and lower the status line.

j) Repeat steps a through h as often as you like.

Discrete I/O Timing Diagram

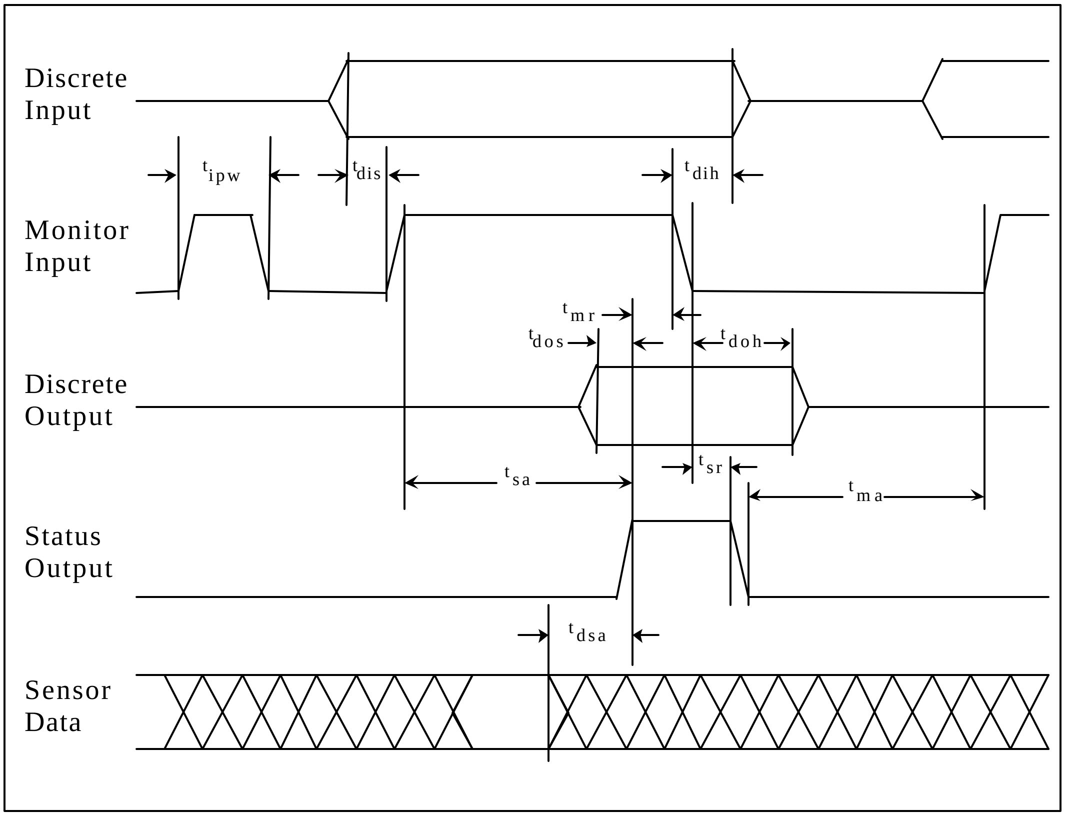


Figure 5.4 Discrete I/O timing diagram

Symbol	Parameter	Notes	Min	Max	Units
T_{dis}	Discrete input setup	Unaffected by Commands	0.00		ms
T_{sa}	Monitor assert to status assert	1 vector enabled, 1 condition	2.00	3.75	ms
		6 vectors, 1 condition, averaging enabled	2.60	4.20	ms
		6 vectors, 8 conditions, averaging enabled	2.70	4.60	ms
		6 vectors, 32 conditions, averaging enabled	3.20	4.85	ms
T_{dsa}	Sensor data to status assert	1 vector enabled, 1 condition	0.65	2.15	ms
		6 vectors, 1 condition, averaging enabled	1.00	2.25	ms
		6 vectors, 8 conditions, averaging enabled	1.30	2.40	ms
		6 vectors, 32 conditions, averaging enabled	1.80	2.95	ms
T_{dos}	Discrete output setup	Unaffected by Commands	0.55	0.95	ms
T_{mr}	Status assert to monitor release	Unaffected by Commands	0.00		ms
T_{dih}	Discrete input hold	Unaffected by Commands	0.00		ms
T_{sr}	Monitor release to status release	1 vector enabled, 1 condition	1.30	2.30	ms
		6 vectors, 1 condition, averaging enabled	1.30	2.95	ms
		6 vectors, 8 conditions, averaging enabled	1.30	2.95	ms
		6 vectors, 32 conditions, averaging enabled	1.30	2.95	ms
T_{doh}	Discrete output hold	Unaffected by Commands	1.15	2.45	ms
T_{ma}	Status release to monitor assert	Unaffected by Commands	0.00		ms
T_{ipw}	Ignored pulse width	Unaffected by Commands	0.00	0.55	ms

Notes:

- Signals are measured at the discrete I/O connector.
- Communications port transmissions will slow down response times.
- ^S/^Q handshaking on serial port can stop discrete I/O processing.

Table 5.3 Discrete I/O timing characteristics

Health Line

This line is used in conjunction with the health LED on the front of the F/T Controller. During F/T system normal operating state the health line is “on” and front panel *Error* LED is off. If an error occurs in the F/T system, such as saturation, the health line is turned off and the front panel *Error* LED is turned on.

Bias Line

This line is used to bias the F/T system and works the same as sending the command SB. A bias is taken on a low-to-high transition. There is no provision for unbiasing through the discrete I/O.

A common application would be to bias the resolved force vector just prior to examining the forces and torques. Biasing eliminates drift and gives an accurate force/torque data of the forces applied by the application.

5.4 SERIAL AND DISCRETE I/O ELECTRICAL CHARACTERISTICS

Serial I/O Electrical Characteristics

Absolute Maximum Ratings

Input lines (RS-232 pins 2 and 4)

$V_{in} = \pm 30V$

Output lines short circuit duration (RS-232 pin 3)

$t = \infty$

Parameter	Conditions	Min.	Typ.	Max.	Units
Output Voltage Swing		±5	±9		V
Output Short Circuit Current			±10		mA
Input Voltage Range		-30		+30	V
Input Voltage Threshold Low	$T_A = 25°C$	0.8	1.2		V
Input Voltage Threshold High	$T_A = 25°C$		1.7	2.4	V
Input Hysteresis		0.2	0.5	1.0	V
Input Resistance		3	5	7	kΩ

Table 5.4 Serial I/O electrical characteristics

Discrete I/O Electrical Characteristics

Absolute Maximum Ratings

Input lines (Input bits 0, 1, 2, 3, Monitor, and Bias)

$V_{in} = -24.0V \text{ to } 26.5V$

I_{in} = -85.0mA to 65.0mA

Output lines (Output bits 0, 1, 2, 3, Status, and Health)

V_{ce} = -7.0V to 55.0V

I_c = 50.0mA

Warning...

Do not exceed *Absolute Maximum Ratings* – permanent damage may occur to the F/T Controller.

Parameter	Conditions	Min.	Typ.	Max.	Units
Input Voltage Operating Range	User Supply Voltage	10.0		24.0	V
Input Voltage Threshold Low	$I_{in} \leq 0.7mA$		3.75		V
Input Voltage Threshold High	$I_{in} \geq 0.8mA$		4.50		V
Output Voltage Operating Range		10.0		24.0	V
Output Current Leakage					
Output Collector Current	V=10V, R_L=1.0kΩ		9.6		mA
	V=24V, R_L=1.0kΩ		22.7		mA

Table 5.5 Discrete I/O electrical characteristics

⁂⁂⁂⁂ ⁂⁂⁂⁂ ⁂⁂⁂⁂

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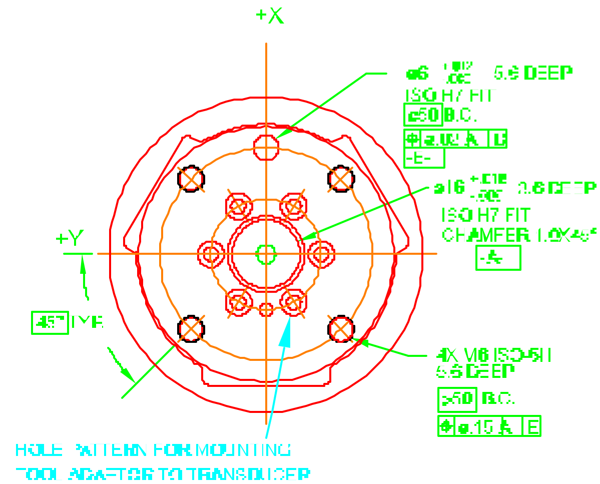
6

Analog Output Option



Section | **Page**

6.1 INTRODUCTION

The Analog Interface Board allows the user to communicate with the controller at faster speeds than the standard RS-232 serial port. The six outputs of the analog interface can represent either F/T values or strain gage data.

> ***Aside…***
>
> ***Fz Analog Output NOTE***: The Fz analog output will not have the maximum voltage output at the rated Fz range. The Fz analog output range is the same as the Fx and Fy range. For example: The Gamma US-30-100 F/T system is calibrated for the Fx and Fy ranges to be 30lb and the Fz will measure up to 100lb, but the Fz analog output will have a maximum output voltage reading at 30lb just like Fx and Fy, not at the specified 100lb range**.**

6.2 ANALOG OUTPUT DESCRIPTION

The analog output port provides analog voltages representing sensor data and an analog update signal for advanced users. The analog outputs are the analog representation of the QS command. The 20-pin analog port connector provides ±5V (optional ±10V available upon request) signals for each of the six possible outputs. See Figure 6.1 and Table 6.2 for analog port pinouts. To reduce potential analog noise, we recommend using twisted-pair ribbon cable in your analog port connections.

Enabling Analog Output Updates

The **CA *b*** command controls the updating of the analog outputs. Entering **CA 1** starts the updating and **CA 0** stops the updating [see *Section 4.2*].

> ***Aside...***
>
> The analog output command defaults to “CA 0” on system initialization, regardless of previous settings. Therefore it is necessary to include an “CA 1” command in the system startup buffer, Zip Macro 0, if you wish to automatically enable analog outputs.

Fast Output Mode

The normal update rate of the system is 752 Hz, but by using the CF command (see *Section 4.2*) you can increase the update rate. You can also increase the update rate by reducing the number of F/T axes output (use the CV command; see *Section 4.2*). If you use the CF or CV command you can use the SF command to select the optimum sampling frequency to give you the fastest update rate.

	Sampling Freq. Default / Optimum (Hz)			
Type of output	**CF 0**	**CF 1**	**CF 2**	**CF 3**
1 F/T axis	752 / 2007	2600 / 2671	2600 / 2818	2600 / 2953
2 F/T axes	752 / 1706	2100 / 2163	2100 / 2258	2100 / 2345
3 F/T axes	752 / 1484	1800 / 1828	1800 / 1884	1800 / 1944
4 F/T axes	752 / 1312	1500 / 1575	1500 / 1616	1500 / 1660
5 F/T axes	752 / 1177	1300 / 1377	1300 / 1415	1300 / 1449
6 F/T axes	752 / 1066	1200 / 1228	1200 / 1259	1200 / 1285
Strain gage data (CD D & CV 3F)	752 / 1066	1200 / 1228	1200 / 1259	1200 / 1285
Strain gage data (CD D & CV 0)	752 / 2226	3000 / 3072	3000 / 3268	3000 / 3451

Table 6.1 Selecting the optimum sampling frequency for various CF and CV commands

Analog Port Pin Assignments

PIN	DESCRIPTION
1	Reserved
3	No connection
5	Reserved
7	Reserved
9	Channel 5 reference
11	Channel 4 reference
13	Channel 3 reference
15	Channel 2 reference
17	Channel 1 reference
19	Channel 0 reference

PIN	DESCRIPTION
2	Reserved
4	No connection
6	Reserved
8	Reserved
10	Channel 5 signal; Tz or SG 5
12	Channel 4 signal; Ty or SG 4
14	Channel 3 signal; Tx, or SG 3
16	Channel 2 signal; Fz or SG 2
18	Channel 1 signal; Fy or SG 1
20	Channel 0 signal; Fx or SG 0

Table 6.2 Analog Port Pin Assignments

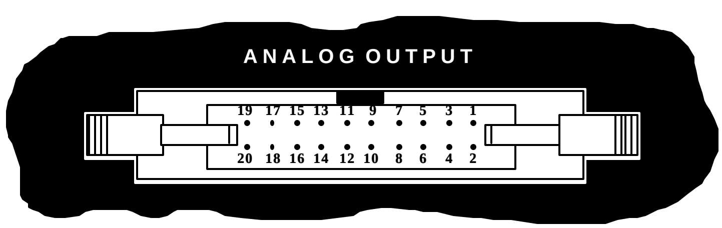


Figure 6.1 Analog Port Connector (20-pin ribbon cable header)

Analog Outputs

The analog port outputs the same data as the query commands (**QS**, **QR** and ^**T**) as voltages. Outputs are scaled so full-scale sensor data is output as a full-scale analog voltage (standard ±5V or optional ±10V). For example, if the F/T is set up with **CD R** (communicate data resolved) command and **CA 1** (communicate analog enabled) command and a rated load is applied to the Fx axis, then the analog output "Channel 0" will be at full-scale voltage.

Analog Output Filtering

As with any digital-to-analog conversion, the analog signals need to be filtered to remove unwanted high-frequency steps (discontinuities) that occur when the output is updated. If these steps are not removed and the user digitizes during a transition, there is a possibility the acquired sample would be invalid. To reduce the likelihood of a bad sample the outputs are filtered to remove the steps. The analog board output filters are factory set for a 1000 Hz update rate.

Changing Analog Output Filtering

The analog filters can be matched to one of two update rates. The first rate is the default of 1000 Hz. The second update rate, factory set to 2500 Hz, is selected by changing jumpers on the analog printed circuit board and using the **FC d** command. Table 6.3 describes the changes necessary under **Filter Selection**. All output channels must have the same filter selection.

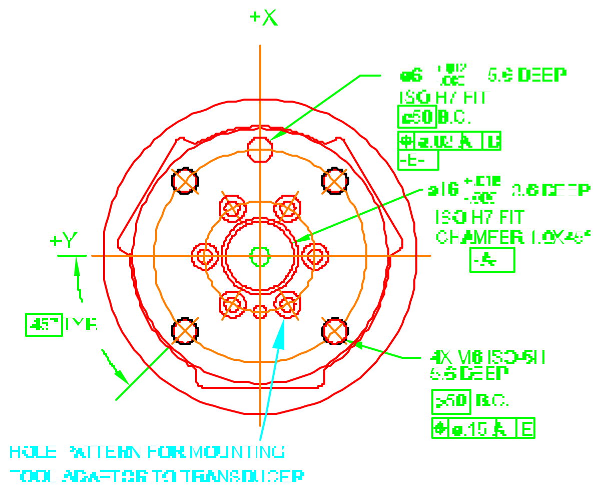
Filter Description	**1000 Hz**	**2500 Hz**
Type	Butterworth	Butterworth
Order	5th	5th
Av @ 1/2 Update Frequency	-52dB	-40dB
Filter Clock command	**FC 81**	**FC 26**
Jumper settings:J1, J2, J5, J6, J9, J10	1.0Khz	2.5Khz

Table 6.3 Analog Filter Characteristics

> ***Aside...***
>
> The filter clock defaults to "FC 81" on system initialization, regardless of previous settings. Therefore it is necessary to include an "FC d" command in the system startup buffer, Zip Macro 0, if the default filter is not used.

7

Trouble-Shooting Guide



Section **Page**

7.1 INTRODUCTION

The answers to some questions and problems that might arise when setting up and using the F/T system are included in this section. The question or problem is listed followed by the probable answer or solution. The questions/problems 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 that may have problems that the manual cannot solve or questions that cannot be answered:

ATI Industrial Automation
Customer Service
Pinnacle Park
1031 Goodworth Drive
Apex, NC 27502 USA

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

Aside...

Please read the manual before calling customer service. Before 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. 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 be near the F/T system when talking with an ATI Industrial Automation customer service representative.

7.2 QUESTIONS AND ANSWERS

Communications

QUESTION/PROBLEM:	ANSWER/SOLUTION:
Random characters appear on the screen while trying to communicate with the F/T controller using a serial device.	The baud rate may not be set correctly. Go into your terminal's setup mode and set the baud rate to 9600. This is the default setting. If problems still occur check baud rate setting, see *Section 1.4*. The serial device attributes may not be correct. The serial attributes should be 8-bit transmission with No Parity and One Stop Bit.
Cannot communicate with the F/T system.	Make sure the serial, Transducer, and power cables are securely connected at both ends. Make sure the serial cable configuration is correct. See *Section 5.1* and *1.4*. Check the power LED to see that the F/T Controller is getting power.
Cannot get the Discrete I/O lines to communicate.	See *Section 5*. Check handshaking and electrical connections. Use the ID and OD commands to check the Discrete I/O connections.

Errors with force and torque readings

Bad data from the transducer's strain gages 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 transmitting raw strain gage data (command CD D) to a terminal.

QUESTION/PROBLEM:	ANSWER/SOLUTION:
Saturation	When the data from a raw decimal strain gage reads -2048 or 2047, that gage is saturated. This generates a saturation error message and causes the red LED to turn on when sensor monitor is enabled, sets the health line low on the discrete I/O and sets the overload bit high. Saturation occurs if the sensor is loaded beyond its rated maximum, or in the event of an electrical failure within the system. The error message will repeat until the saturation error stops. If the "SM 0" command was sent then an error message will not occur, but the LED, health line and overload byte will work. Note: with optional temperature compensation enabled (TC 1), it is possible to have strain gage values reported outside of the -2048..2047 range.
Noise	Jumps in raw strain gage readings (with sensor unloaded) greater than 5 counts is considered abnormal. 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 gage reading does not stabilize but continues to increase or decrease. This may be observed more easily in resolved data mode using the bias command, SB. Drift is caused by temperature change, mechanical coupling or internal failure. Mechanical coupling is caused when a connection is made between the tool plate and the sensor body (i.e. plastic filings between the tool adaptor 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, gage readings do not return quickly and completely to their original readings. Hysteresis is caused by mechanical coupling (explained in drift section) or internal failure.

7.3 ERROR MESSAGES

When an error occurs a message is sent over the serial. The error message is made of the following items:

a) NAK as the first byte.
b) A capital "E" follows.
c) An error number follows and consists of a three number sequence in ASCII mode, but one byte in Binary mode.
d) An error description no longer than 80 bytes follows the error number.
e) A carriage return and line feed follows the error description and marks the end of the error message. A line feed will not be sent if it has been disabled with the CL command.
f) Another carriage return and line feed follow.
g) The prompt is the last item shown.

System and user communications	Comments
`>L`	*ìLî is entered by mistake*
`E114 Illegal command`	*Error message is displayed. The <NAK> is not displayed. <CR><LF>*
`>`	*are sent followed by ì>î prompt.*

Figure 7.1 Error message example

Error #	Error description	Comment
100 thru 107	Gauge *n* saturation	*n* represents last digit in error # (10*n*)
108	Input buffer overrun	User is sending data too quickly
109	Output buffer overrun	
110	Command too long	
111	Output buffer failure	
112	Illegal input port	
113	Illegal output port	
114	Illegal command	
115	X-axis force saturation	The rated load is exceeded in the axis shown
116	Y-axis force saturation	
117	Z-axis force saturation	
118	XYZ-axes torque saturation	
119	Illegal monitor condition operand	

Table 7.1 Error message overview (continued)

Error #	Error description	Comment
120	Illegal output format	
121	Illegal output type	
122	A/D not converting	Internal error to controller
123	A/D still converting	Internal error to controller
124	Illegal filtering	
125	Illegal resolved data	
126	Output buffer full	
127	Illegal format	Check format of command
128	Value out of range	Commands that use a value
129	No monitor condition(s)	Deleting a monitor condition
130	Buffer is full	
131	Command aborted	
132	Corrupted memory	Internal error to controller
133	Illegal vector	
134	Incorrect response received	
135	Illegal baud rate	Internal error to controller
136	Serial port overrun	
137	Serial port framing error	
138	No response received	
139	Option is not installed	
140	Illegal average filtering value	
141	String too long	Commands requiring a string
142	Monitor condition(s) full	Loading in a new monitor condition
143	Unable to send `<X-Off>`	
144	Unable to send `<X-On>`	
145	DMA not ready	
146	DMA did not read	
147	DMA not empty	
148	Zero tool frame	You cannot select a tool frame that has not been constructed with TC command except factory installed calibration matrices
149	Illegal tool frame index	
150	Sensor Error	This will occur if the transducer is disconnected or broken.

Table 7.1 Error message overview (continued)

A

Stand-alone Transducer Specifications

A.1 GENERAL SPECIFICATIONS

Storage and Operating Temperatures

The transducer, mux box, and controller can be stored and used at varying temperatures. If you will be using the transducer with temperatures varying significantly from room temperature then use the temperature compensation so that the F/T values will be corrected as the temperature changes. Below are the temperature specifications:

	Storage Temperature, ºC	Operating Temperature, ºC
Transducer	-65 to 150	0 to 70
Mux box	-65 to 150	0 to 70
Stand-alone controller	-40 to 100	0 to 55

Table A.1 Storage and operating temperatures

Input Filter Frequency Response

The input filter in the transducer or mux box electronics is used to prevent aliasing.

Figure A.1 Input filter frequency response (-3dB @ 235Hz)

A.2 TRANSDUCER AND CALIBRATION SPECIFICATIONS

These tables list specifications for standard transducer models in both English (US) and metric (SI) units.

Nano17

	English (US)			Metric (SI)		
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 lb	±6 lb	±12 lb	±12.0 N	±25 N	±50 N
Fz	±4.25 lb	±8.5 lb	±17 lb	±17 N	±35 N	±70 N
Tx, Ty, Tz	±1 in-lb	±2 in-lb	±4 in-lb	±120 Nmm	±250 Nmm	±500 Nmm
Resolution (minimum)						
Fx, Fy	1/320 lb	1/160 lb	1/80 lb	1/80 N	1/40 N	1/20 N
Fz	1/320 lb	1/160 lb	1/80 lb	1/80 N	1/40 N	1/20 N
Tx, Ty, Tz	1/2000 in-lb	1/1000 in-lb	1/500 in-lb	1/16 Nmm	1/8 Nmm	1/4 Nmm
Counts Value						
Fx, Fy, Fz	320 / lb	160 / lb	80 / lb	80 / N	40 / N	20 / N
Tx, Ty, Tz	2000 / in-lb	1000 / in-lb	500 / in-lb	16 / Nmm	8 / Nmm	4 / Nmm
Analog Output						
Analog Range						
Fx, Fy	±3 lb	±6 lb	±12 lb	±12 N	±25 N	±50 N
Fz	±3 lb	±6 lb	±12 lb	±12 N	±25 N	±50 N
Tx, Ty, Tz	±1 in-lb	±2 in-lb	±4 in-lb	±120 Nmm	±250 Nmm	±500 Nmm
± 5 V Sensitivity						
Fx, Fy	0.6 lb/V	1.2 lb/V	2.4 lb/V	2.4 N/V	5 N/V	10 N/V
Fz	0.6 lb/V	1.2 lb/V	2.4 lb/V	2.4 N/V	5 N/V	10 N/V
Tx, Ty, Tz	0.2 in-lb/V	0.4 in-lb/V	0.8 in-lb/V	24 Nmm/V	50 Nmm/V	100 Nmm/V
± 10 V Sensitivity						
Fx, Fy, Fz	0.3 lb/V	0.6 lb/V	1.2 lb/V	1.2 N/V	2.5 N/V	5 N/V
Fz	0.3 lb/V	0.6 lb/V	1.2 lb/V	1.2 N/V	2.5 N/V	5 N/V
Tx, Ty, Tz	0.1 in-lb/V	0.2 in-lb/V	0.4 in-lb/V	12 Nmm/V	25 Nmm/V	50 Nmm/V
Tool Transform Factor	0.0016 in/unit	0.0016 in/un	0.0016 in/unit	0.05 mm/unit	0.05 mm/unit	0.05 mm/unit

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	53×10^3 lb/in	9.3×10^6 N/m
Z-axis force (Kz)	69×10^3 lb/in	12×10^6 N/m
X-axis and Y-axis torque (Ktx, Kty)	2.2×10^3 in-lb/rad	250 Nm/rad
Z-axis torque (Ktz)	3.5×10^3 in-lb/rad	390 Nm/rad
Resonant Frequency (Measured)		
Fx, Fy, Tz	7.2 kHz	
Fz, Tx, Ty	7.2 kHz	
Maximum Single-axis Load		
Fx, Fy	±79 lb	±350 N
Fz	±180 lb	±820 N
Tx, Ty	±23 in-lb	±2.6 Nm
Tz	±28 in-lb	±3.1 Nm
Weight		
Transducer with standard plates	0.021 lb (0.33 oz)	9.4 g
Material		
Transducer	Hardened Stainless Steel	
Mounting and tool adapters	Aircraft Aluminum	

Nano25

	English (US)		Metric (SI)	
Calibration	**US-25-25**	**US-50-50**	**SI-125-3**	**SI-250-6**
Rated Sensing Ranges				
Fx, Fy	±25 lb	±50 lb	±125 N	±250 N
Fz	±100 lb	±200 lb	±500 N	±1000 N
Tx, Ty	±25 in-lb	±50 in-lb	±3 Nm	±6 Nm
Tz	±25 in-lb	±50 in-lb	±3 Nm	±3.4 Nm
Resolution (minimum)				
Fx, Fy	1/56 lb	1/28 lb	1/12 N	1/6 N
Fz	3/56 lb	3/28 lb	1/4 N	1/2 N
Tx, Ty,	1/40 in-lb	1/20 in-lb	1/330 Nmm	1/165 Nmm
Tz	1/80 in-lb	1/40 in-lb	1/660 Nmm	1/330 Nmm
Counts Value				
Fx, Fy, Fz	56 / lb	28 / lb	12 / N	6 / N
Tx, Ty, Tz	80 / in-lb	40 / in-lb	660 / Nm	330 / Nm
Analog Output				
Analog Range				
Fx, Fy	±25 lb	±50 lb	±125 N	±250 N
Fz	±25 lb	±50 lb	±125 N	±250 N
Tx, Ty, Tz	±25 in-lb	±50 in-lb	±3 Nm	±6 Nm
± 5 V Sensitivity				
Fx, Fy	5 lb/V	10 lb/V	25 N/V	50 N/V
Fz	5 lb/V	10 lb/V	25 N/V	50 N/V
Tx, Ty, Tz	5 in-lb/V	10 in-lb/V	0.6 Nm/V	1.2 Nm/V
± 10 V Sensitivity				
Fx, Fy, Fz	2.5 lb/V	5 lb/V	12.5 N/V	25 N/V
Fz	2.5 lb/V	5 lb/V	12.5 N/V	25 N/V
Tx, Ty, Tz	2.5 in-lb/V	5 in-lb/V	0.3 Nm/V	0.6 Nm/V
Tool Transform Factor	0.007 in/unit	0.007 in/unit	181.82×10^{-6} mm/unit	181.82×10^{-6} mm/unit

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	300×10^{3} lb/in	53×10^{6} N/m
Z-axis force (Kz)	630×10^{3} lb/in	110×10^{6} N/m
X-axis and Y-axis torque (Ktx, Kty)	57×10^{3} in-lb/rad	6440 Nm/rad
Z-axis torque (Ktz)	82×10^{3} in-lb/rad	9260 Nm/rad
Resonant Frequency (Measured)		
Fx, Fy, Tz	3.6 kHz	
Fz, Tx, Ty	3.8 kHz	
Maximum Single-axis Load		
Fx, Fy	±520 lb	±2300 N
Fz	±1400 lb	±6300 N
Tx, Ty	±310 in-lb	±35 Nm
Tz	±560 in-lb	±63 Nm
Weight		
Transducer with standard plates	0.14 lb	65 g
Material		
Transducer	Hardened Stainless Steel	
Mounting and tool adapters	Hardened Stainless Steel	

Nano43

	English (US)		Metric (SI)	
Calibration	**US-4-2**	**US-8-4**	**SI-18-0.25**	**SI-36-0.5**
Rated Sensing Ranges				
Fx, Fy	±4 lb	±8 lb	±18 N	±36 N
Fz	±4 lb	±8 lb	±18 N	±36 N
Tx, Ty	±2 in-lb	±4 in-lb	±250 Nmm	±500 Nmm
Tz	±2 in-lb	±4 in-lb	±250 Nmm	±500 Nmm
Resolution (minimum)				
Fx, Fy	1/290 lb	1/145 lb	1/64 N	1/32 N
Fz	1/290 lb	1/145 lb	1/64 N	1/32 N
Tx, Ty,	1/580 in-lb	1/64 in-lb	1/5000 Nmm	1/2500 Nmm
Tz	1/580 in-lb	1/64 in-lb	1/5000 Nmm	1/2500 Nmm
Counts Value				
Fx, Fy, Fz	290 / lb	145 / lb	64 / N	32 / N
Tx, Ty, Tz	580 / in-lb	290 / in-lb	5 / Nmm	2.5 / Nmm
Analog Output				
Analog Range				
Fx, Fy	±4 lb	±8 lb	±18 N	±36 N
Fz	±4 lb	±8 lb	±18 N	±36 N
Tx, Ty, Tz	±2 in-lb	±4 in-lb	±250 Nmm	±500 Nmm
± 5 V Sensitivity				
Fx, Fy	0.8 lb/V	1.6 lb/V	3.6 N/V	7.2 N/V
Fz	0.8 lb/V	1.6 lb/V	3.6 N/V	7.2 N/V
Tx, Ty, Tz	0.4 in-lb/V	0.8 in-lb/V	50 Nmm/V	100 Nmm/V
± 10 V Sensitivity				
Fx, Fy, Fz	0.4 lb/V	0.8 lb/V	1.8 N/V	3.6 N/V
Fz	0.4 lb/V	0.8 lb/V	1.8 N/V	3.6 N/V
Tx, Ty, Tz	0.2 in-lb/V	0.4 in-lb/V	25 Nmm/V	50 Nmm/V
Tool Transform Factor	0.5 in/unit	0.5 in/unit	0.0128 mm/unit	0.0128 mm/unit

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	30×10^3 lb/in	5.2×10^6 N/m
Z-axis force (Kz)	30×10^3 lb/in	5.2×10^6 N/m
X-axis and Y-axis torque (Ktx, Kty)	6.8×10^3 in-lb/rad	770 Nm/rad
Z-axis torque (Ktz)	10×10^3 in-lb/rad	1.1×10^3 Nm/rad
Maximum Single-axis Load		
Fx, Fy	±68 lb	±300 N
Fz	±89 lb	±400 N
Tx, Ty	±30 in-lb	±3.4 Nm
Tz	±48 in-lb	±5.4 Nm
Weight		
Transducer with standard plates	0.085 lb	39 g
Material		
Transducer	Hardened Stainless Steel	
Mounting and tool adapters	Aircraft Aluminum	

Mini40

	English (US)			Metric (SI)		
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 lb	±10 lb	±20 lb	±20 N	±40 N	±80 N
Fz	±15 lb	±30 lb	±60 lb	±60 N	±120 N	±240 N
Tx, Ty, Tz	±10 in-lb	±20 in-lb	±40 in-lb	±1 Nm	±2 Nm	±4 Nm
Resolution (minimum)						
Fx, Fy	1/200 lb	1/100 lb	1/50 lb	1/50 N	1/25 N	2/25 N
Fz	1/200 lb	1/100 lb	1/50 lb	1/25 N	2/25 N	4/25 N
Tx, Ty, Tz	1/200 in-lb	1/100 in-lb	1/50 in-lb	1/2000 Nmm	1/1000 Nmm	1/500 Nmm
Counts Value						
Fx, Fy	200 / lb	100 / lb	50 / lb	50 / N	25 / N	12.5 / N
Tx, Ty, Tz	200 / in-lb	100 / in-lb	50 / in-lb	2000 / Nm	1000 / Nm	500 / Nm
Analog Output						
Analog Range						
Fx, Fy	±5 lb	±10 lb	±20 lb	±20 N	±40 N	±80 N
Fz	±5 lb	±10 lb	±20 lb	±20 N	±40 N	±80 N
Tx, Ty, Tz	±10 in-lb	±20 in-lb	±40 in-lb	±1 Nm	±2 Nm	±4 Nm
± 5 V Sensitivity						
Fx, Fy	1 lb/V	2 lb/V	4 lb/V	4 N/V	8 N/V	16 N/V
Fz	1 lb/V	2 lb/V	4 lb/V	4 N/V	8 N/V	16 N/V
Tx, Ty, Tz	2 in-lb/V	4 in-lb/V	8 in-lb/V	0.2 Nm/V	0.4 Nm/V	0.8 Nm/V
± 10 V Sensitivity						
Fx, Fy, Fz	0.5 lb/V	1 lb/V	2 lb/V	2 N/V	4 N/V	8 N/V
Fz	0.5 lb/V	1 lb/V	2 lb/V	2 N/V	4 N/V	8 N/V
Tx, Ty, Tz	1 in-lb/V	2 in-lb/V	4 in-lb/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

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	65×10^3 lb/in	11×10^6 Nm
Z-axis force (Kz)	134×10^3 lb/in	23×10^6 Nm
X-axis and Y-axis torque (Ktx, Kty)	29×10^3 in-lb/rad	3300 Nm/rad
Z-axis torque (Ktz)	38×10^3 in-lb/rad	4300 Nm/rad
Resonant Frequency (Measured)		
Fx, Fy, Tz	3.2 kHz	
Fz, Tx, Ty	4.9 kHz	
Maximum Single-axis Load		
Fx, Fy	±200 lb	±890 N
Fz	±610 lb	±2700 N
Tx, Ty	±190 in-lb	±22 Nm
Tz	±190 in-lb	±21 Nm
Weight		
Transducer with standard plates	0.11 lb	50 g
Material		
Transducer	Hardened Stainless Steel	
Mounting and tool adapters	Aircraft Aluminum	

Mini45

	English (US)			Metric (SI)		
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 lb	±60 lb	±120 lb	±145 N	±290 N	±580 N
Fz	±60 lb	±120 lb	±240 lb	±290 N	±580 N	±1160 N
Tx, Ty, Tz	±40 in-lb	±80 in-lb	±160 in-lb	±5 Nm	±10 Nm	±20 Nm
Resolution (minimum)						
Fx, Fy	1/40 lb	1/20 lb	1/10 lb	1/8 N	1/4 N	1/2 N
Fz	1/20 lb	1/10 lb	1/5 lb	1/4 N	1/2 N	1 N
Tx, Ty, Tz	1/44 in-lb	1/22 in-lb	1/11 in-lb	1/376 Nmm	1/188 Nmm	1/94 Nmm
Counts Value						
Fx, Fy	40 / lb	20 / lb	10 / lb	8 / N	4 / N	2 / N
Tx, Ty, Tz	44 / in-lb	22 / in-lb	11 / in-lb	376 / Nm	188 / Nm	94 / Nm
Analog Output						
Analog Range						
Fx, Fy	±30 lb	±60 lb	±120 lb	±145 N	±290 N	±580 N
Fz	±30 lb	±60 lb	±120 lb	±145 N	±290 N	±580 N
Tx, Ty, Tz	±40 in-lb	±80 in-lb	±160 in-lb	±5 Nm	±10 Nm	±20 Nm
± 5 V Sensitivity						
Fx, Fy	6 lb/V	12 lb/V	24 lb/V	29 N/V	58 N/V	116 N/V
Fz	6 lb/V	12 lb/V	24 lb/V	29 N/V	58 N/V	116 N/V
Tx, Ty, Tz	8 in-lb/V	16 in-lb/V	32 in-lb/V	1 Nm/V	2 Nm/V	4 Nm/V
± 10 V Sensitivity						
Fx, Fy, Fz	3 lb/V	6 lb/V	12 lb/V	14.5 N/V	29 N/V	58 N/V
Fz	3 lb/V	6 lb/V	12 lb/V	14.5 N/V	29 N/V	58 N/V
Tx, Ty, Tz	4 in-lb/V	8 in-lb/V	16 in-lb/V	0.5 Nm/V	1 Nm/V	2 Nm/V
Tool Transform Factor	9.0909×10^{-3} in/unit	9.0909×10^{-3} in/unit	9.0909×10^{-3} in/unit	212.8×10^{-6} mm/unit	212.8×10^{-6} mm/unit	212.8×10^{-6} mm/unit

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	430×10^{3} lb/in	75×10^{6} Nm
Z-axis force (Kz)	560×10^{3} lb/in	98×10^{6} Nm
X-axis and Y-axis torque (Ktx, Kty)	150×10^{3} in-lb/rad	17 Nm/rad
Z-axis torque (Ktz)	310×10^{3} in-lb/rad	35 Nm/rad
Resonant Frequency (Measured)		
Fx, Fy, Tz	3.2 kHz	
Fz, Tx, Ty	4.9 kHz	
Maximum Single-axis Load		
Fx, Fy	±1200 lb	±5100 N
Fz	±2300 lb	±10000 N
Tx, Ty, Tz	±950 in-lb	±110 Nm
Tx, Ty, Tz	±1200 in-lb	±140 Nm
Weight		
Transducer with standard plates	0.20 lb	92 g
Material		
Transducer	Hardened Stainless Steel	
Mounting and tool adapters	Aircraft Aluminum	

Gamma

	English (US)			Metric (SI)		
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 lb	±15 lb	±30 lb	±32 N	±65 N	±130 N
Fz	±25 lb	±50 lb	±100 lb	±100 N	±200 N	±400 N
Tx, Ty, Tz	±25 in-lb	±50 in-lb	±100 in-lb	±2.5 Nm	±5 Nm	±10 Nm
Resolution (minimum)						
Fx, Fy	1/160 lb	1/80 lb	1/40 lb	1/40 N	1/20 N	1/10 N
Fz	1/80 lb	1/40 lb	1/20 lb	1/20 N	1/10 N	1/5 N
Tx, Ty	1/80 in-lb	1/40 in-lb	1/20 in-lb	1/500 Nm	3/1000 Nm	1/200 Nm
Tz	1/80 in-lb	1/40 in-lb	1/20 in-lb	1/500 Nm	3/1000 Nm	1/200 Nm
Counts Value						
Fx, Fy, Fz	160 / lb	80 / lb	40 / lb	40 / N	20 / N	10 / N
Tx, Ty, Tz	160 / in-lb	80 / in-lb	40 / in-lb	500 / Nm	333.33 / Nm	200 / Nm
Analog Output						
Analog Range						
Fx, Fy	±7.5 lb	±15 lb	±30 lb	±32 N	±65 N	±130 N
Fz	±7.5 lb	±15 lb	±30 lb	±32 N	±65 N	±130 N
Tx, Ty, Tz	±25 in-lb	±50 in-lb	±100 in-lb	±2.5 Nm	±5 Nm	±10 Nm
± 5 V Sensitivity						
Fx, Fy	1.5 lb/V	3.0 lb/V	6.0 lb/V	6.4 N/V	13 N/V	26 N/V
Fz	1.5 lb/V	3.0 lb/V	6.0 lb/V	6.4 N/V	13 N/V	26 N/V
Tx, Ty, Tz	5.0 in-lb/V	10 in-lb/V	20 in-lb/V	0.5 Nm/V	1.0 Nm/V	2.0 Nm/V
± 10 V Sensitivity						
Fx, Fy, Fz	0.75 lb/V	1.5 lb/V	3.0 lb/V	3.2 N/V	6.5 N/V	13 N/V
Fz	0.75 lb/V	1.5 lb/V	3.0 lb/V	3.2 N/V	6.5 N/V	13 N/V
Tx, Ty, Tz	2.5 in-lb/V in-	5.0 in-lb/V	10 in-lb/V	0.25 Nm/V	0.5 Nm/V	1.0 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

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	52×10^3 lb/in	9.1×10^6 N/m
Z-axis force (Kz)	100×10^3 lb/in	18×10^6 N/m
X-axis and Y-axis torque (Ktx, Kty)	93×10^3 in-lb/rad	11×10^3 Nm/rad
Z-axis torque (Ktz)	140×10^3 in-lb/rad	16×10^3 Nm/rad
Resonant Frequency (Measured)		
Fx, Fy, Tz	1.4 kHz	
Fz, Tx, Ty	2.0 kHz	
Maximum Single-axis Load		
Fx, Fy	±270 lb	±1200 N
Fz	±910 lb	±4100 N
Tx, Ty	±690 in-lb	±79 Nm
Tz	±730 in-lb	±82 Nm
Weight		
Transducer with standard 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
Material		
Transducer	Aircraft Aluminum	
Standard mounting adapter	Aircraft Aluminum	
Ring/Plug adapters	Aircraft Aluminum	

Delta

	English (US)			Metric (SI)		
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 lb	±75 lb	±150 lb	±165 N	±330 N	±660 N
Fz	±150 lb	±225 lb	±450 lb	±495 N	±990 N	±1980 N
Tx, Ty, Tz	±150 in-lb	±300 in-lb	±600 in-lb	±15 Nm	±30 Nm	±60 Nm
Resolution (minimum)						
Fx, Fy	1/32 lb	1/16 lb	1/8 lb	1/8 N	1/4 N	1/2 N
Fz	1/16 lb	1/8 lb	1/4 lb	1/4 N	1/2 N	1 N
Tx, Ty	3/32 in-lb	3/16 in-lb	3/8 in-lb	1/132 Nm	3/200 Nm	3/100 Nm
Tz	1/16 in-lb	1/8 in-lb	1/4 in-lb	1/132 Nm	3/200 Nm	3/100 Nm
Counts Value						
Fx, Fy, Fz	32 / lb	16 / lb	8 / lb	8 / N	4 / N	2 / N
Tx, Ty, Tz	32 / in-lb	16 / in-lb	8 / in-lb	133.3 / Nm	66.7/Nm	33.33/Nm
Analog Output						
Analog Range						
Fx, Fy	±37.5 lb	±75 lb	±150 lb	±165 N	±330 N	±660 N
Fz	±37.5 lb	±75 lb	±150 lb	±165 N	±330 N	±660 N
Tx, Ty, Tz	±150 in-lb	±300 in-lb	±600 in-lb	±15 Nm	±30 Nm	±60 Nm
± 5 V Sensitivity						
Fx, Fy	7.5 lb/V	15 lb/V	30 lb/V	33 N/V	66 N/V	132 N/V
Fz	7.5 lb/V	15 lb/V	30 lb/V	33 N/V	66 N/V	132 N/V
Tx, Ty, Tz	30 in-lb/V	60 in-lb/V	120 in-lb/V	3 Nm	6 Nm/V	12 Nm/V
± 10 V Sensitivity						
Fx, Fy, Fz	3.75 lb/V	7.5 lb/V	15 lb/V	16.5 N/V	33 N/V	66 N/V
Fz	3.75 lb/V	7.5 lb/V	15 lb/V	16.5 N/V	33 N/V	66 N/V
Tx, Ty, Tz	15 lb/V	30 in-lb/V	60 in-lb/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	0.6 mm/unit	0.6 mm/unit	0.6 mm/unit

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	210×10^3 lb/in	37×10^6 N/m
Z-axis force (Kz)	350×10^3 lb/in	61×10^6 N/m
X-axis and Y-axis torque (Ktx, Kty)	460×10^3 in-lb/rad	52×10^3 Nm/rad
Z-axis torque (Ktz)	830×10^3 in-lb/rad	94×10^3 Nm/rad
Resonant Frequency (Measured)		
Fx, Fy, Tz	1.5 kHz	
Fz, Tx, Ty	1.7 kHz	
Maximum Single-axis Load		
Fx, Fy	±770 lb	±3400 N
Fz	±2600 lb	±12,000 N
Tx, Ty,	±2000 in-lb	±220 Nm
Tz	±3700 in-lb	±420 Nm
Weight		
Transducer with standard plates	2.0 lb	910 g
Transducer with ring/plug TAP	2.6 lb	1152 g
Transducer with ring/plug MAP	2.7 lb	1236 g
Material		
Transducer	R_c32 Stainless Steel	
Standard mounting adapter	Aircraft Aluminum	

Theta

	English (US)			Metric (SI)		
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 lb	±300 lb	±600 lb	±1000 N	±1500 N	±2500 N
Fz	±500 lb	±875 lb	±1500 lb	±2500 N	±3750 N	±6250N
Tx, Ty, Tz	±1000 in-lb	±1800 in-lb	±3600 in-lb	±120 Nm	±240 Nm	±400 Nm
Resolution (minimum)						
Fx, Fy	1/8 lb	5/17 lb	1/2 lb	1 N	1 N	2 N
Fz	1/4 lb	10/17 lb	1 lb	1 N	2 N	3 N
Tx, Ty, Tz	1/2 in-lb	5/4 in-lb	2 in-lb	1/20 Nm	1/10 Nm	1/20 Nm
Counts Value						
Fx, Fy, Fz	8 / lb	3.4 / lb	2 / lb	2 / N	1 / N	1 / N
Tx, Ty, Tz	4 / in-lb	0.8 / in-lb	1 / in-lb	20 / Nm	10 / Nm	5 / Nm
Analog Output						
Analog Range						
Fx, Fy	±200 lb	±300 lb	±600 lb	±1000 N	±1500 N	±2500 N
Fz	±200 lb	±300 lb	±600 lb	±1000 N	±1500 N	±2500 N
Tx, Ty, Tz	±1000 in-lb	±1800 in-lb	±3600 in-lb	±120 Nm	±240 Nm	±400 Nm
± 5 V Sensitivity						
Fx, Fy	40 lb/V	60 lb/V	120 lb/V	200 N/V	300 N/V	500 N/V
Fz	40 lb/V	60 lb/V	120 lb/V	200 N/V	300 N/V	500 N/V
Tx, Ty, Tz	200 in-lb/V	360 in-lb/V	720 in-lb/V	24 Nm	48 Nm	80 Nm
± 10 V Sensitivity						
Fx, Fy, Fz	20 lb/V	30 lb/V	60 lb/V	100 N/V	150 N/V	250 N/V
Fz	20 lb/V	30 lb/V	60 lb/V	100 N/V	150 N/V	250 N/V
Tx, Ty, Tz	100 lb/V	180 in-lb/V	360 in-lb/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

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	420×10^3 lb/in	73.0×10^6 N/m
Z-axis force (Kz)	710×10^3 lb/in	125×10^6 N/m
X-axis and Y-axis torque (Ktx, Kty)	3.0×10^6 in-lb/rad	3.4×10^5 Nm/rad
Z-axis torque (Ktz)	4.8×10^6 in-lb/rad	5.4×10^5 Nm/rad
Resonant Frequency (Measured)		
Fx, Fy, Tz	680 Hz	
Fz, Tx, Ty	820 Hz	
Maximum Single-axis Load		
Fx, Fy	±5700 lb	±25,000N
Fz	±14,000 lb	±61,000 N
Tx, Ty	±22,000 in-lb	±2500 Nm
Tz	±24,000 in-lb	±2700 Nm
Weight		
Transducer with standard plates	9.5 lb	4300 g
Material		
Transducer	R_c32 Stainless Steel	
Standard mounting adapter	Aircraft Aluminum	

Omega160

	English (US)			Metric (SI)		
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 lb	±300 lb	±600 lb	±1000 N	±1500 N	±2500 N
Fz	±500 lb	±875 lb	±1500 lb	±2500 N	±3750 N	±6250N
Tx, Ty, Tz	±1000 in-lb	±1800 in-lb	±3600 in-lb	±120 Nm	±240 Nm	±400 Nm
Resolution (minimum)						
Fx, Fy	1/8 lb	5/17 lb	1/2 lb	1 N	1 N	2 N
Fz	1/4 lb	10/17 lb	1 lb	1 N	2 N	3 N
Tx, Ty, Tz	1/2 in-lb	5/4 in-lb	2 in-lb	1/20 Nm	1/10 Nm	1/20 Nm
Counts Value						
Fx, Fy, Fz	8 / lb	3.4 / lb	2 / lb	2 / N	1 / N	1 / N
Tx, Ty, Tz	4 / in-lb	0.8 / in-lb	1 / in-lb	20 / Nm	10 / Nm	5 / Nm
Analog Output						
Analog Range						
Fx, Fy	±200 lb	±300 lb	±600 lb	±1000 N	±1500 N	±2500 N
Fz	±200 lb	±300 lb	±600 lb	±1000 N	±1500 N	±2500 N
Tx, Ty, Tz	±1000 in-lb	±1800 in-lb	±3600 in-lb	±120 Nm	±240 Nm	±400 Nm
± 5 V Sensitivity						
Fx, Fy	40 lb/V	60 lb/V	120 lb/V	200 N/V	300 N/V	500 N/V
Fz	40 lb/V	60 lb/V	120 lb/V	200 N/V	300 N/V	500 N/V
Tx, Ty, Tz	200 in-lb/V	360 in-lb/V	720 in-lb/V	24 Nm	48 Nm	80 Nm
± 10 V Sensitivity						
Fx, Fy, Fz	20 lb/V	30 lb/V	60 lb/V	100 N/V	150 N/V	250 N/V
Fz	20 lb/V	30 lb/V	60 lb/V	100 N/V	150 N/V	250 N/V
Tx, Ty, Tz	100 lb/V	180 in-lb/V	360 in-lb/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

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	400×10^3 lb/in	70.0×10^6 N/m
Z-axis force (Kz)	680×10^3 lb/in	120×10^6 N/m
X-axis and Y-axis torque (Ktx, Kty)	2.9×10^6 in-lb/rad	3.3×10^5 Nm/rad
Z-axis torque (Ktz)	4.7×10^6 in-lb/rad	5.3×10^5 Nm/rad
Resonant Frequency (Measured)		
Fx, Fy, Tz	1.3 kHz	
Fz, Tx, Ty	1.0 kHz	
Maximum Single-axis Load		
Fx, Fy	±4000 lb	±18,000N
Fz	±11,000 lb	±48,000 N
Tx, Ty, Tz	±15,000 lb	±1700 Nm
Tx, Ty, Tz	±17,000 lb	±1900 Nm
Weight		
Transducer with standard plates	6.0 lb	2700 g
Material		
Transducer	Hardened Stainless Steel	
Mounting and tool adapters	Aircraft Aluminum	

Omega190

	English (US)			Metric (SI)		
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 lb	±800 lb	±1600 lb	±1800 N	±3600 N	±7200 N
Fz	±1000 lb	±2000 lb	±4000 lb	±4500 N	±9000 N	±18000 N
Tx, Ty, Tz	±3000 in-lb	±6000 in-lb	±12000 in-lb	±350 Nm	±700 Nm	±1400 Nm
Resolution (minimum)						
Fx, Fy	5/16 lb	5/8 lb	5/4 lb	3/2 N	3 N	6 N
Fz	5/8 lb	5/4 lb	5/2 lb	5/2 N	5 N	10 N
Tx, Ty	5/32 in-lb	5/16 in-lb	5/8 in-lb	5/24 Nm	5/12 Nm	5/6 Nm
Tz	5/48 in-lb	5/24 in-lb	5/12 in-lb	5/36 Nm	5/18 Nm	5/9 Nm
Counts Value						
Fx, Fy, Fz	9.6 / lb	4.8 / lb	2 / lb	2 / N	1 / N	0.5 / N
Tx, Ty, Tz	1.6 / in-lb	0.8 / in-lb	0.4 / in-lb	14.4 / Nm	7.2 / Nm	3.6 Nm
Analog Output						
Analog Range						
Fx, Fy	±400 lb	±800 lb	±1600 lb	±1800 N	±3600 N	±7200 N
Fz	±400 lb	±800 lb	±1600 lb	±1800 N	±3600 N	±7200 N
Tx, Ty, Tz	±3000 in-lb	±6000 in-lb	±12000 in-lb	±350 Nm	±700 Nm	±1400 Nm
± 5 V Sensitivity						
Fx, Fy	80 lb/V	160 lb/V	320 lb/V	360 N/V	720 N/V	1440 N/V
Fz	80 lb/V	160 lb/V	320 lb/V	360 N/V	720 N/V	1440 N/V
Tx, Ty, Tz	600 in-lb/V	1200 in-lb/V	2400 in-lb/V	70 Nm	140 Nm	280 Nm
± 10 V Sensitivity						
Fx, Fy, Fz	40 lb/V	80 lb/V	160 lb/V	180 N/V	360 N/V	720 N/V
Fz	40 lb/V	80 lb/V	160 lb/V	180 N/V	360 N/V	720 N/V
Tx, Ty, Tz	300 lb/V	600 in-lb/V	1200 in-lb/V	35 Nm/V	70 Nm/V	140 Nm/V
Tool Transform Factor	0.06 in/unit	0.06 in/unit	0.06 in/unit	1.389×10^{-3} mm/unit	1.389×10^{-3} mm/unit	1.389×10^{-3} mm/unit

Physical Properties	**US**	**Metric**
Stiffness (Calculated)		
X-axis and Y-axis force (Kx, Ky)	1.4×10^{6} lb/in	250×10^{6} N/m
Z-axis force (Kz)	2.1×10^{6} lb/in	370×10^{6} N/m
X-axis and Y-axis torque (Ktx, Kty)	14×10^{6} in-lb/rad	1.6×10^{6} Nm/rad
Z-axis torque (Ktz)	14×10^{6} in-lb/rad	3.3×10^{6} Nm/rad
Maximum Single-axis Load		
Fx, Fy	±8000 lb	±36,000 N
Fz	±25,000 lb	±110,000 N
Tx, Ty, Tz	±49,000 lb	±5500 Nm
Tx, Ty, Tz	±72,000 lb	±8100 Nm
Weight		
Transducer with standard plates	14 lb	6.4 kg
Material		
Transducer	Hardened Stainless Steel	
Mounting and tool adapters	Aircraft Aluminum	

A.3 COMPOUND LOADING RANGES OF F/T SENSORS

The F/T sensor's strain gages 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.

These graphs 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 following sample graph 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 gage saturation condition.
C. Extended operating region. In this region, the sensor will operate correctly, but the full-scale accuracy is not guaranteed.

Nano17 (US Calibration)

: Nano17 US-12-4 : Nano17 US-6-2 : Nano17 US-3-1

Nano17 (SI Calibration)

: Nano17 SI-50-0.5 : Nano17 SI-25-0.25 : Nano17 SI-12-0.12

Nano25 (US Calibration)

: Nano25 US-50-50 : Nano25 US-25-25

Nano25 (SI Calibration)

: Nano25 SI-250-6 : Nano25 SI-125-3

Nano43 (US Calibration)

: Nano43 US-8-4

: Nano43 US-4-2

Nano43 (SI Calibration)

: Nano43 SI-36-0.5 : Nano43 SI-18-0.25

Mini40 (US Calibration)

: Mini40 US-20-40 : Mini40 US-10-20 : Mini40 US-5-10

Mini40 (SI Calibration)

: Mini40 SI-80-4 : Mini40 SI-40-2 : Mini40 SI-20-1

Mini45 (US Calibration)

: Mini45 US-120-160 : Mini45 US-60-80 : Mini45 US-30-40

Mini45 (SI Calibration)

: Mini45 SI-580-20 : Mini45 SI-290-10 : Mini45 SI-145-5

Gamma (US Calibration)

: Gamma US-30-100 : Gamma US-15-50 : Gamma US-7.5-25

Gamma (SI Calibration)

: Gamma SI-130-10 : Gamma SI-65-5 : Gamma SI-32-2.5

Delta (US Calibration)

: Delta US-150-600 : Delta US-75-300 : Delta US-50-150

Delta (SI Calibration)

: Delta SI-660-60 : Delta SI-330-30 : Delta SI-165-15

Theta (US Calibration)

: Theta US-600-3600 : Theta US-300-1800 : ThetaUS-200-1000

Theta (SI Calibration)

: Theta SI-2500-400 : Theta SI-1500-240 : Theta SI-1000-120

Omega160 (US Calibration)

: Omega160 US-600-3600 : Omega160 US-300-1800 : Omega160 US- 200-1000

Omega160 (SI Calibration)

: Omega160 SI-2500-400 : Omega160 SI-1500-240 : Omega160 SI-1000-120

Omega190 (US Calibration)

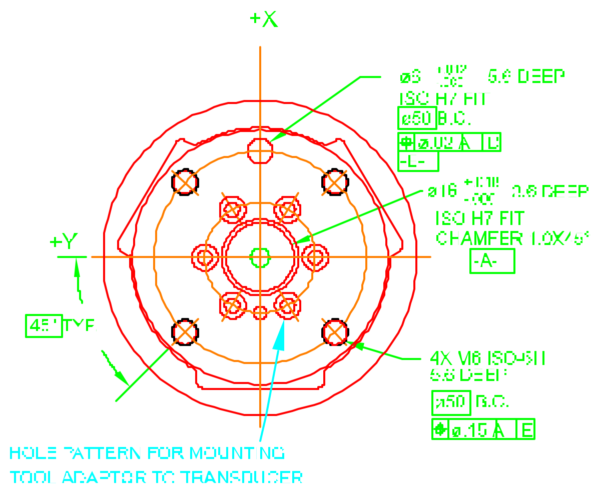
: Omega190 US-1600-12000 : Omega190 US-800-6000 : Omega190 US- 400-3000

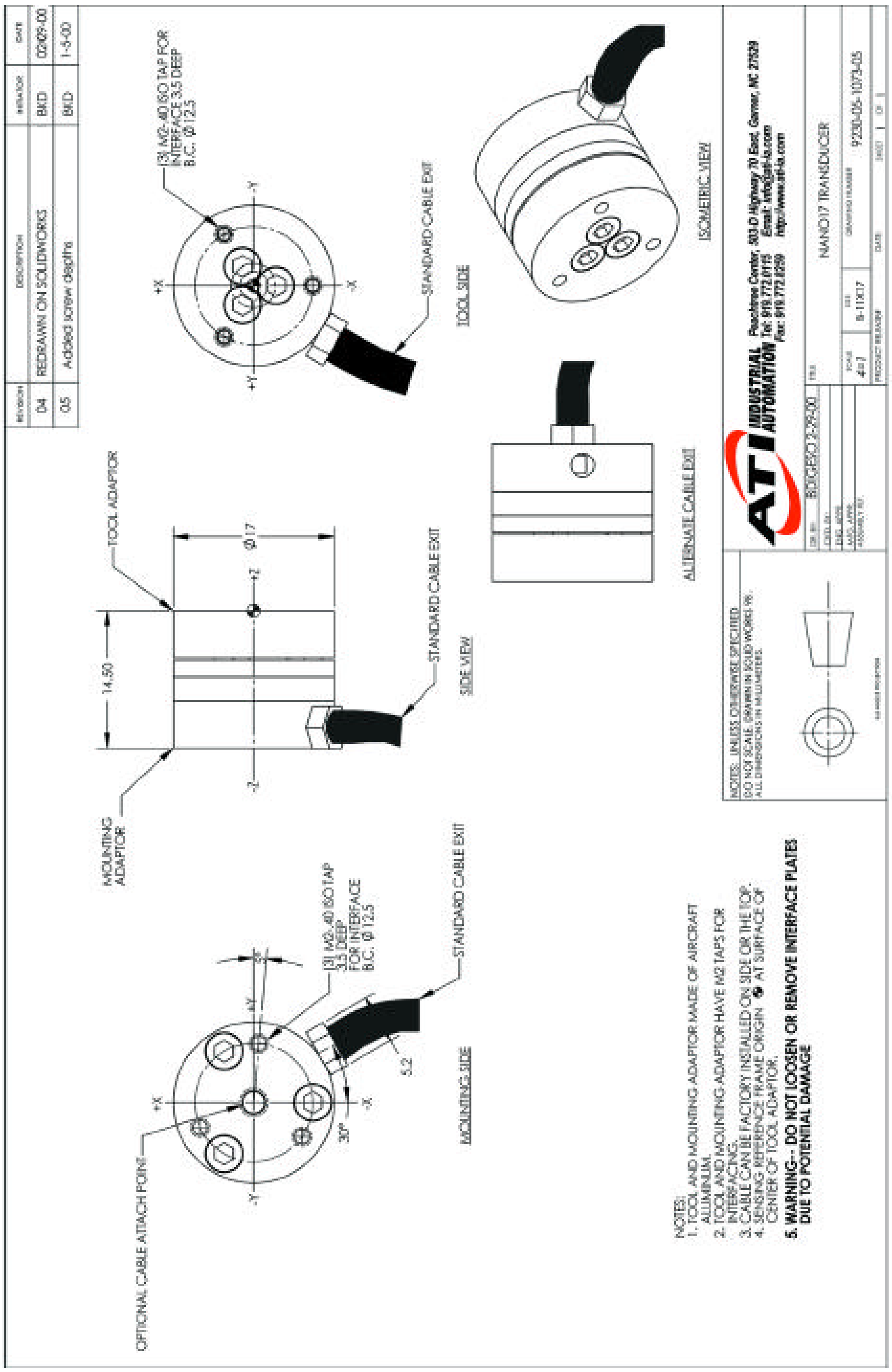
Omega190 (SI Calibration)

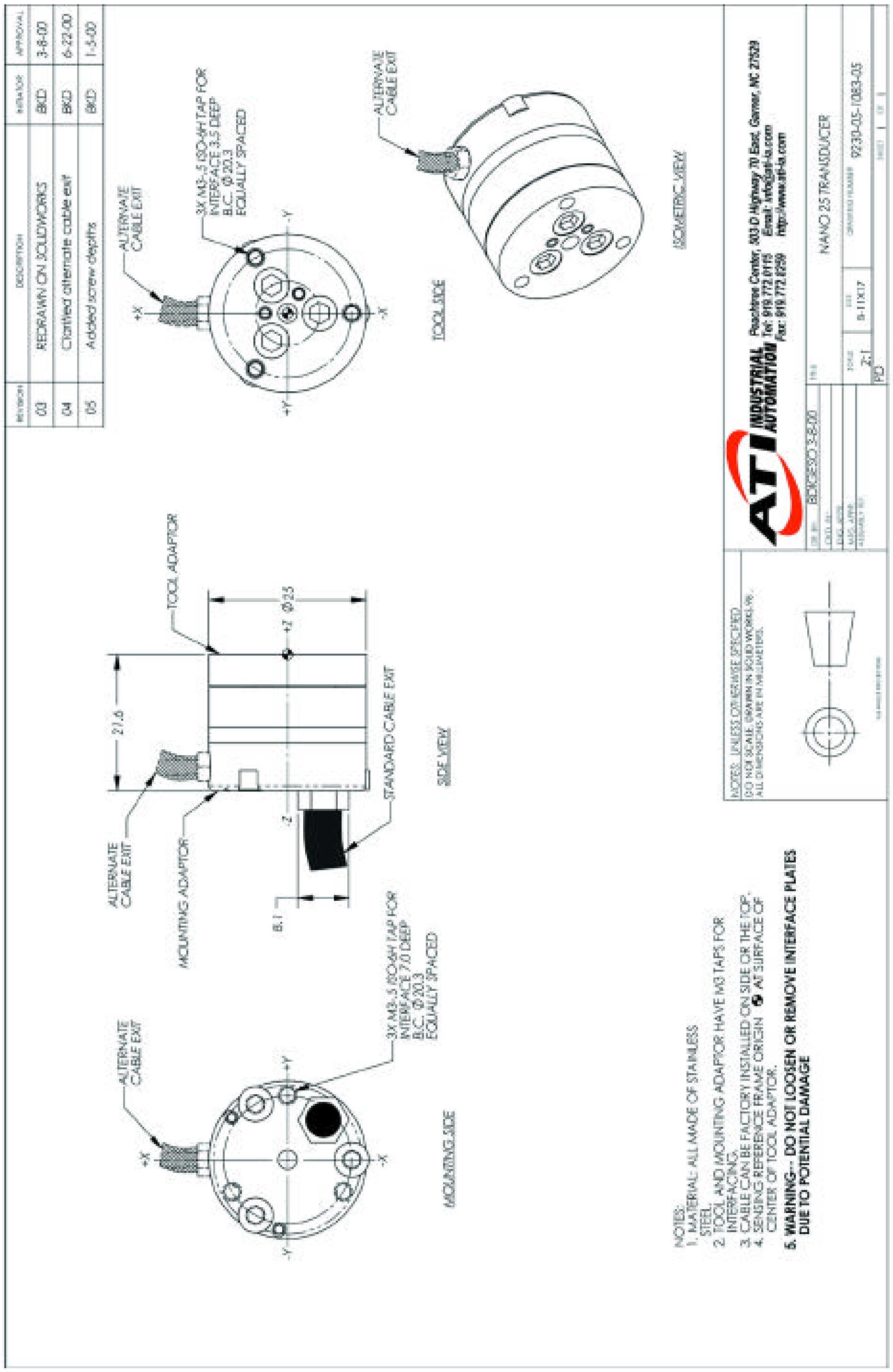
: Omega190 SI-7200-1400 : Omega190 SI-3600-700 : Omega190 SI-1800-350

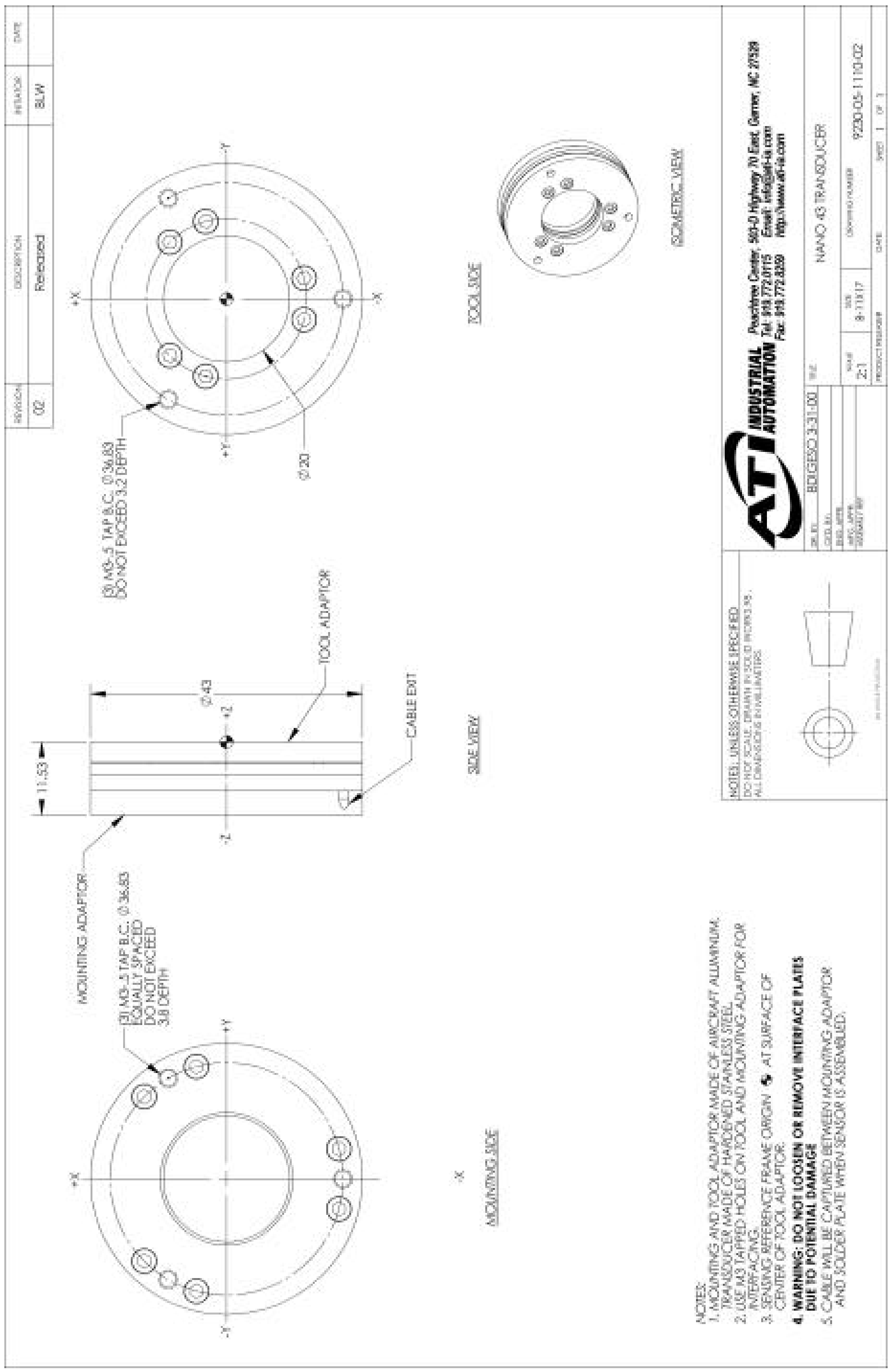
B

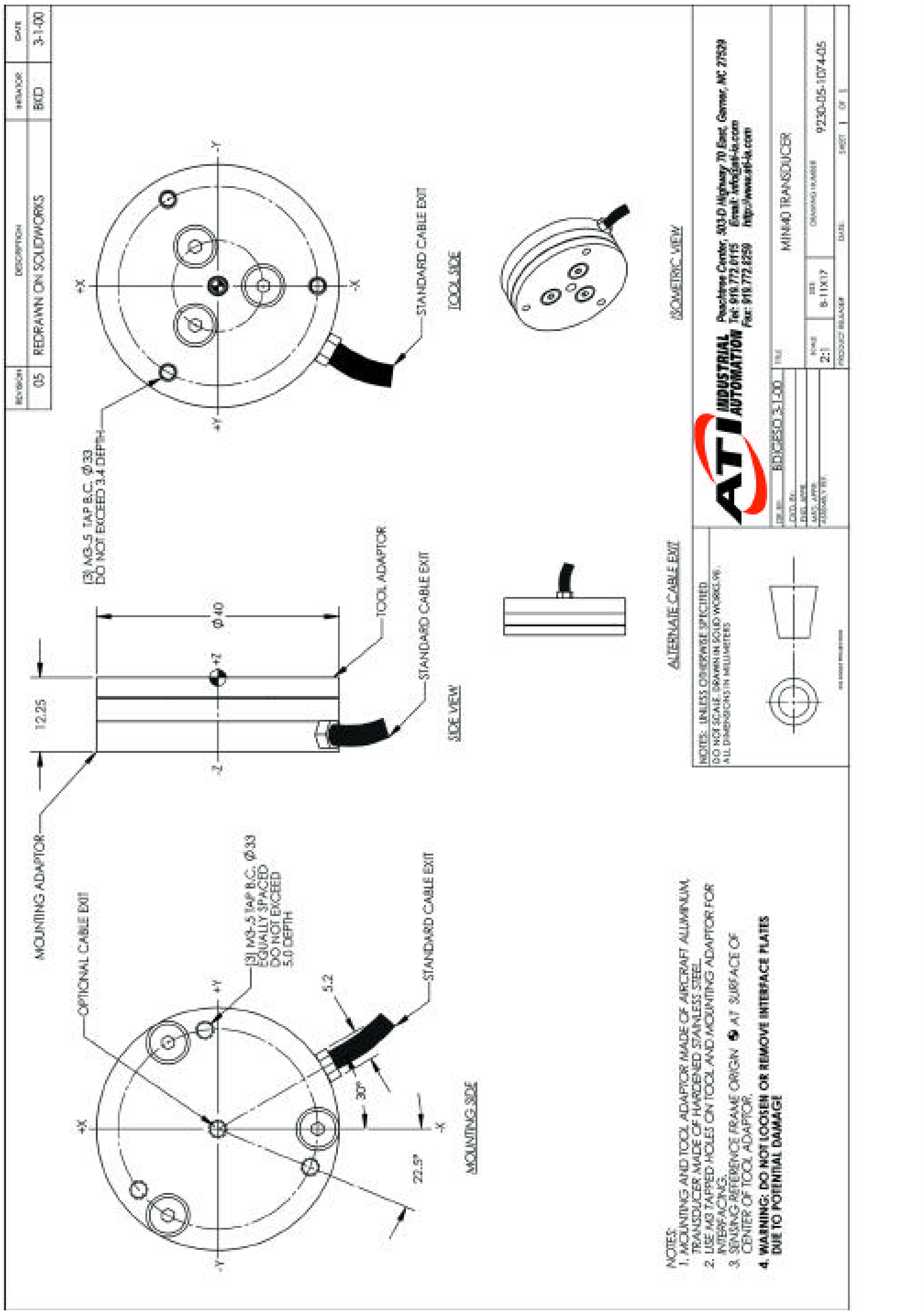
Mechanical Layout

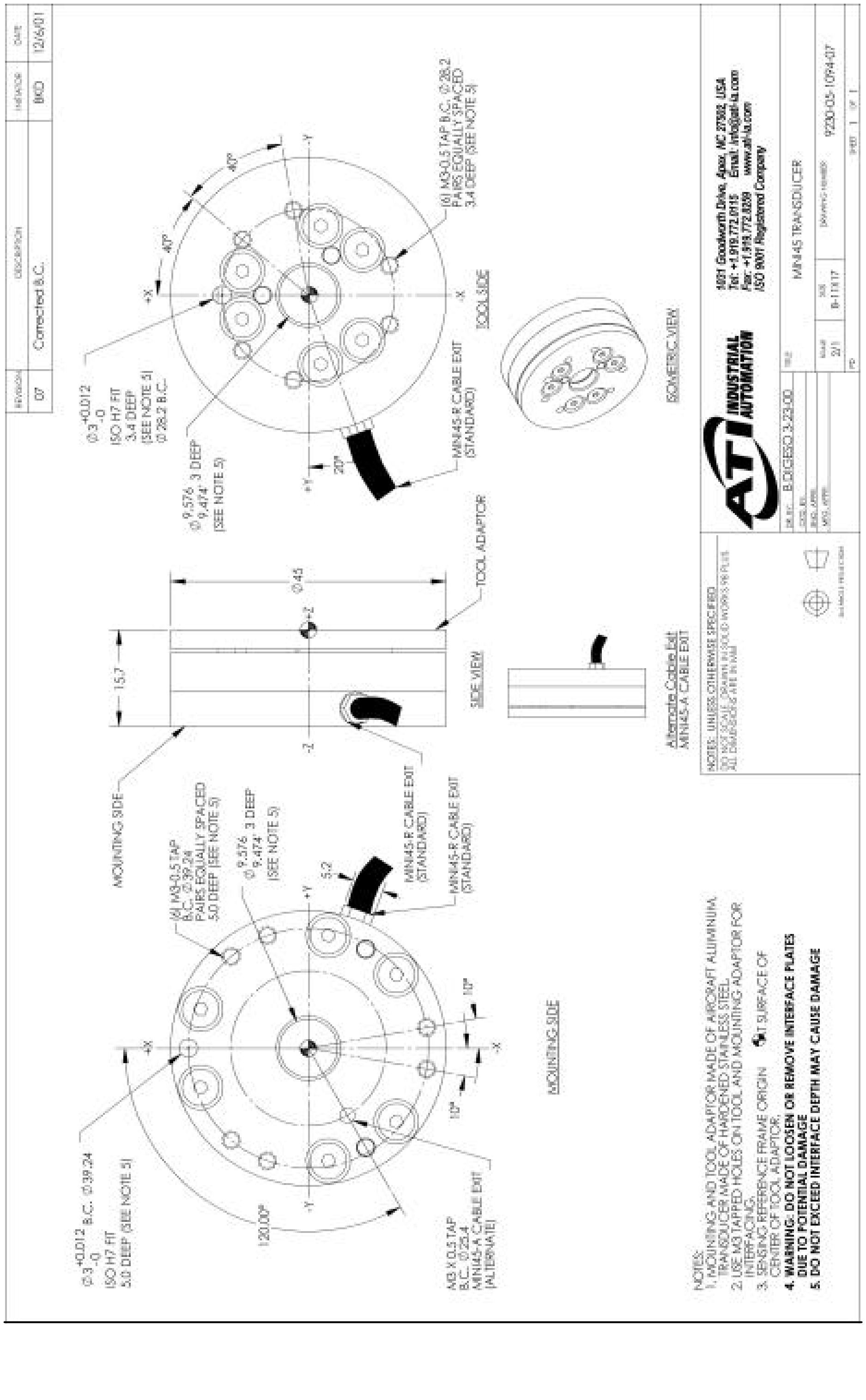


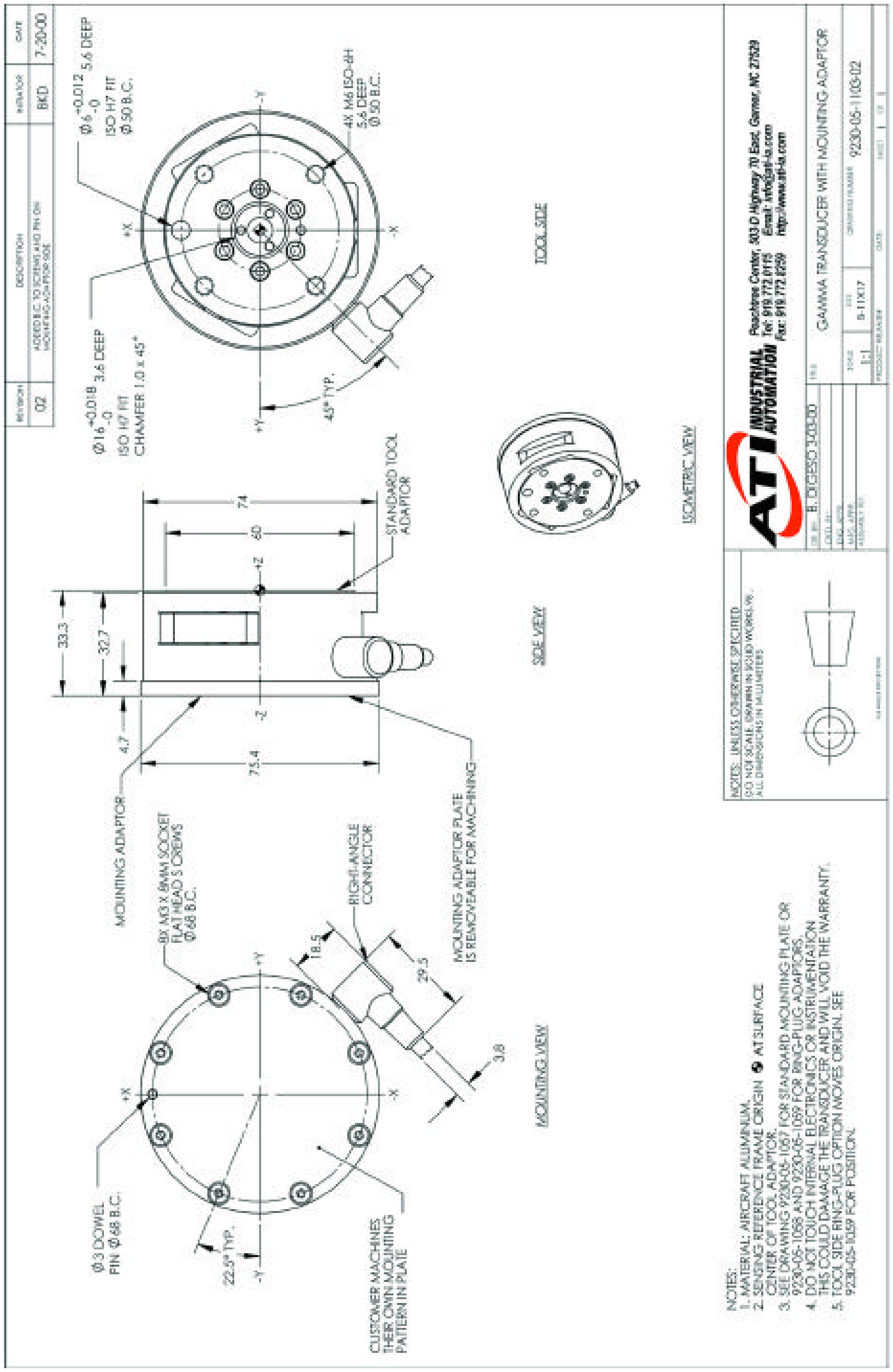

REDRAWN ON SOLIDWORKS
Added screw depths
TOOL ADAPTOR
MOUNTING ADAPTOR
14.50
Ø17
STANDARD CABLE EXIT
SIDE VIEW
TOOL SIDE
MOUNTING SIDE
ISOMETRIC VIEW
ALTERNATE CABLE EXIT
OPTIONAL CABLE ATTACH POINT
(3) M2-.40 ISO TAP FOR INTERFACE 3.5 DEEP B.C. Ø 12.5
(3) M2-.40 ISO TAP 3.5 DEEP FOR INTERFACE B.C. Ø 12.5
NOTES:
1. TOOL AND MOUNTING ADAPTOR MADE OF AIRCRAFT ALUMINUM.
2. TOOL AND MOUNTING ADAPTOR HAVE M2 TAPS FOR INTERFACING.
3. CABLE CAN BE FACTORY INSTALLED ON SIDE OR THE TOP.
4. SENSING REFERENCE FRAME ORIGIN AT SURFACE OF CENTER OF TOOL ADAPTOR.
5. WARNING-- DO NOT LOOSEN OR REMOVE INTERFACE PLATES DUE TO POTENTIAL DAMAGE
ATI INDUSTRIAL AUTOMATION
NANO17 TRANSDUCER
9230-05-1073-05

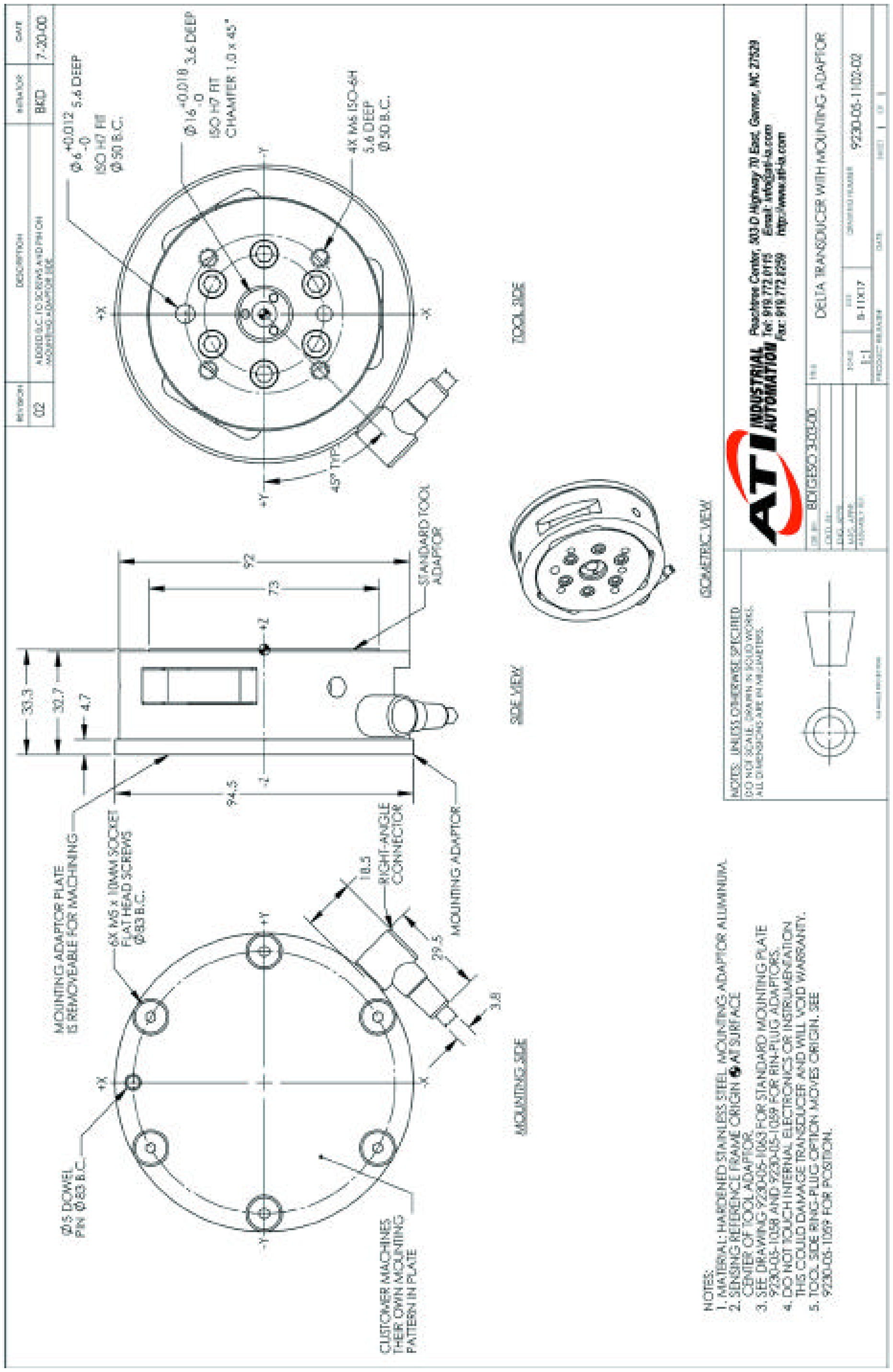


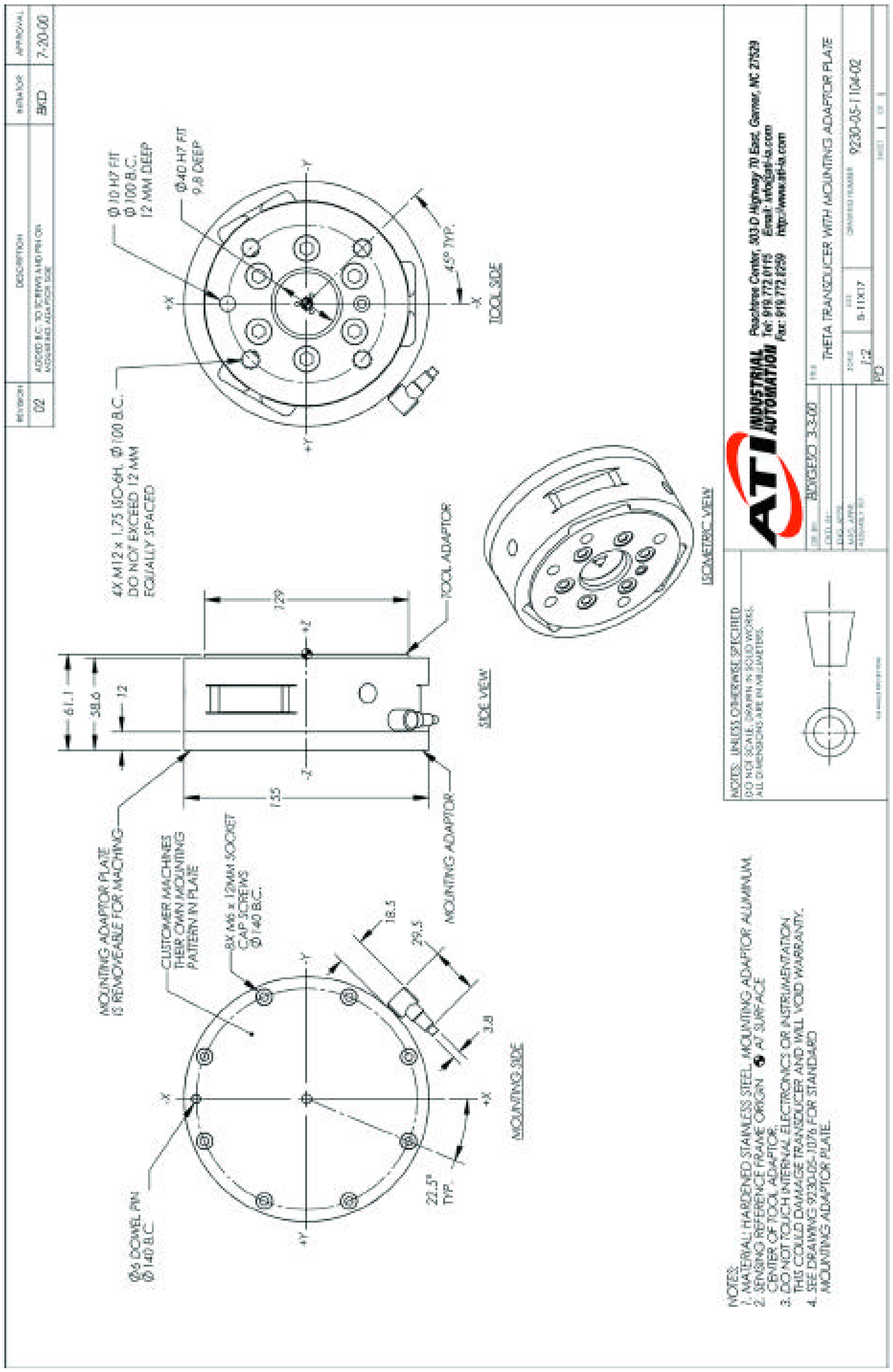

MOUNTING SIDE
SIDE VIEW
TOOL SIDE
ISOMETRIC VIEW
MOUNTING ADAPTOR
TOOL ADAPTOR
CABLE EXIT
NANO 43 TRANSDUCER
9230-05-1110-02
Released
BLW

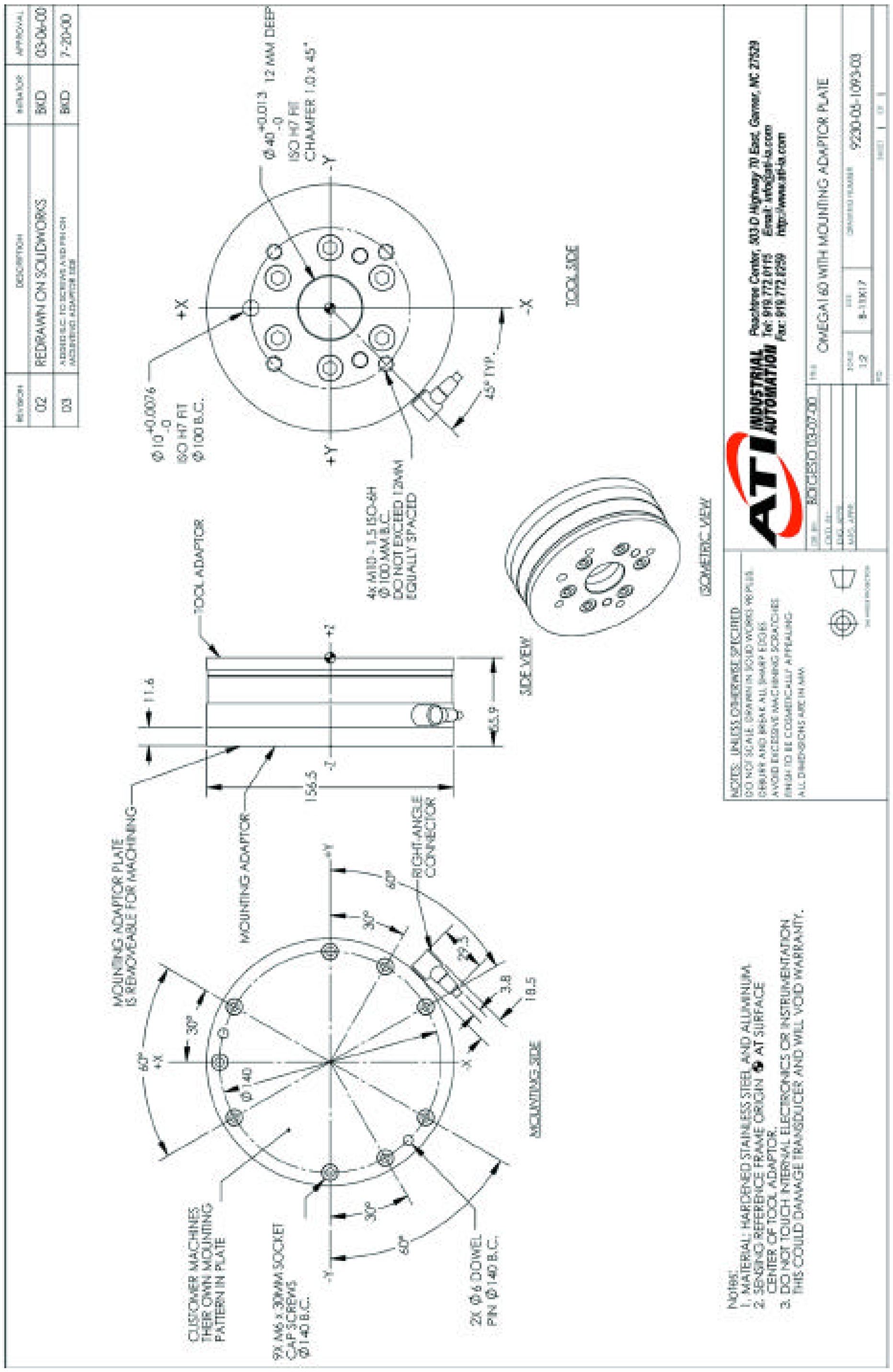

MOUNTING SIDE
TOOL SIDE
SIDE VIEW
ISOMETRIC VIEW
ALTERNATE CABLE EXIT
MOUNTING ADAPTOR
TOOL ADAPTOR
OPTIONAL CABLE EXIT
STANDARD CABLE EXIT
(3) M3-5 TAP B.C. Ø33 EQUALLY SPACED DO NOT EXCEED 5.0 DEPTH
(3) M3-5 TAP B.C. Ø33 DO NOT EXCEED 3.4 DEPTH
12.25
Ø40
REDRAWN ON SOLIDWORKS
MINI40 TRANSDUCER
9230-05-1074-05
NOTES:
1. MOUNTING AND TOOL ADAPTOR MADE OF AIRCRAFT ALUMINUM, TRANSDUCER MADE OF HARDENED STAINLESS STEEL.
2. USE M3 TAPPED HOLES ON TOOL AND MOUNTING ADAPTOR FOR INTERFACING.
3. SENSING REFERENCE FRAME ORIGIN AT SURFACE OF CENTER OF TOOL ADAPTOR.
4. WARNING: DO NOT LOOSEN OR REMOVE INTERFACE PLATES DUE TO POTENTIAL DAMAGE


MOUNTING SIDE
SIDE VIEW
TOOL SIDE
ISOMETRIC VIEW
TOOL ADAPTOR
MINI45-R CABLE EXIT (STANDARD)
M3 X 0.5 TAP B.C. Ø25.4 MINI45-A CABLE EXIT (ALTERNATE)
Alternate Cable Exit MINI45-A CABLE EXIT
Corrected B.C.
12/6/01
NOTES:
1. MOUNTING AND TOOL ADAPTOR MADE OF AIRCRAFT ALUMINUM, TRANSDUCER MADE OF HARDENED STAINLESS STEEL.
2. USE M3 TAPPED HOLES ON TOOL AND MOUNTING ADAPTOR FOR INTERFACING.
3. SENSING REFERENCE FRAME ORIGIN AT SURFACE OF CENTER OF TOOL ADAPTOR.
4. WARNING: DO NOT LOOSEN OR REMOVE INTERFACE PLATES DUE TO POTENTIAL DAMAGE
5. DO NOT EXCEED INTERFACE DEPTH MAY CAUSE DAMAGE
ATI INDUSTRIAL AUTOMATION
MINI45 TRANSDUCER
9230-05-1094-07

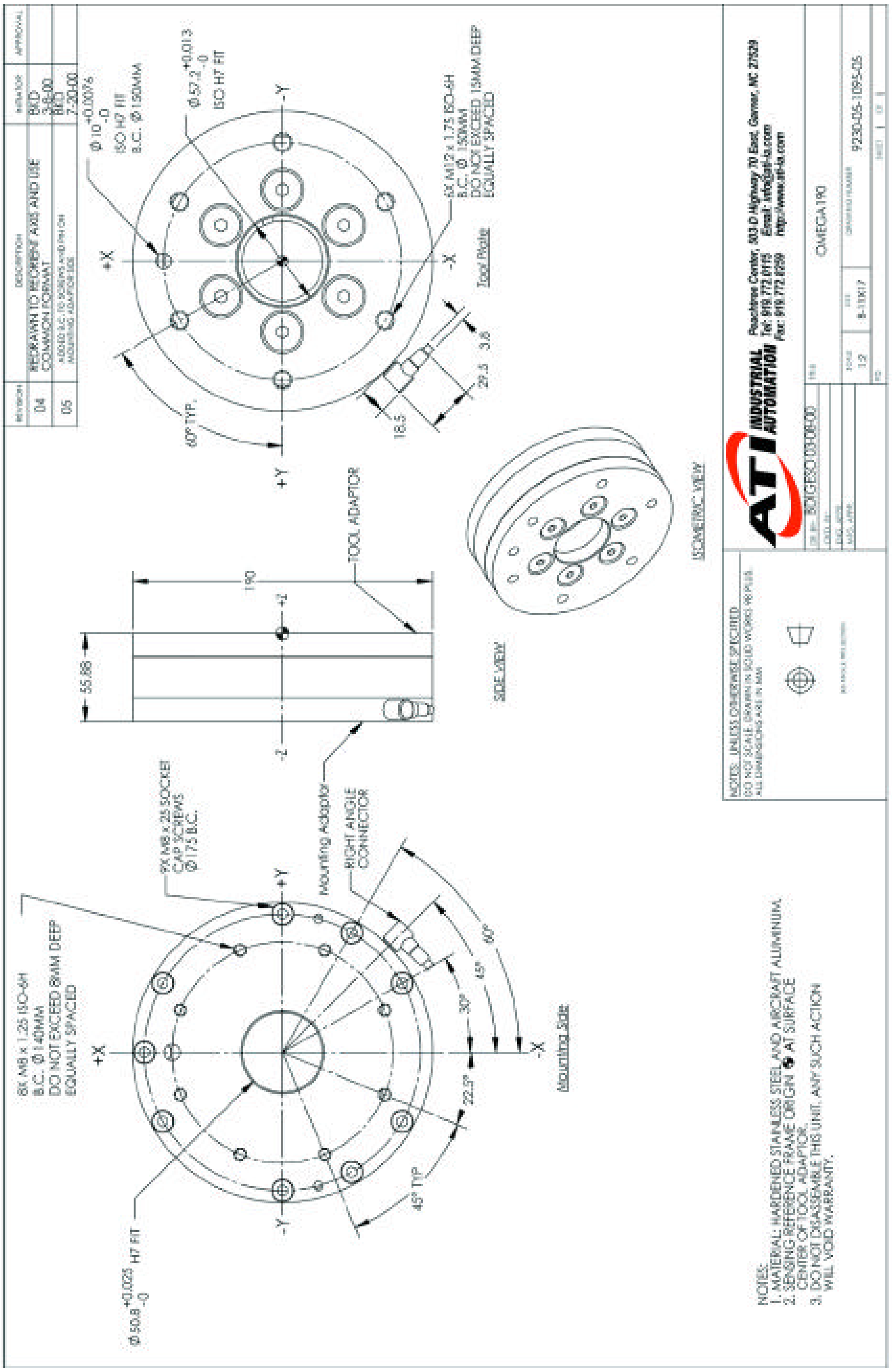



REVISION
DESCRIPTION
INITIATOR
DATE
02
ADDED B.C. TO SCREWS AND PIN ON MOUNTING ADAPTOR SIDE
BKD
7-20-00
Ø5 DOWEL PIN Ø83 B.C.
MOUNTING ADAPTOR PLATE IS REMOVEABLE FOR MACHINING
6X M5 x 10MM SOCKET FLAT HEAD SCREWS Ø83 B.C.
CUSTOMER MACHINES THEIR OWN MOUNTING PATTERN IN PLATE
18.5
RIGHT-ANGLE CONNECTOR
29.5
3.8
MOUNTING ADAPTOR
MOUNTING SIDE
33.3
32.7
4.7
94.5
92
73
STANDARD TOOL ADAPTOR
SIDE VIEW
Ø6 +0.012 -0 5.6 DEEP ISO H7 FIT Ø50 B.C.
Ø16 +0.018 -0 3.6 DEEP ISO H7 FIT CHAMFER 1.0 x 45°
45° TYP
4X M6 ISO-6H 5.6 DEEP Ø50 B.C.
TOOL SIDE
ISOMETRIC VIEW
NOTES:
1. MATERIAL: HARDENED STAINLESS STEEL. MOUNTING ADAPTOR ALUMINUM.
2. SENSING REFERENCE FRAME ORIGIN AT SURFACE CENTER OF TOOL ADAPTOR.
3. SEE DRAWING 9230-05-1063 FOR STANDARD MOUNTING PLATE 9230-05-1058 AND 9230-05-1059 FOR RIN-PLUG ADAPTORS.
4. DO NOT TOUCH INTERNAL ELECTRONICS OR INSTRUMENTATION THIS COULD DAMAGE TRANSDUCER AND WILL VOID WARRANTY.
5. TOOL SIDE RING-PLUG OPTION MOVES ORIGIN. SEE 9230-05-1059 FOR POSITION.
NOTES: UNLESS OTHERWISE SPECIFIED
DO NOT SCALE. DRAWN IN SOLID WORKS.
ALL DIMENSIONS ARE IN MILLIMETERS.
ATI INDUSTRIAL AUTOMATION
Peachtree Center, 503-D Highway 70 East, Garner, NC 27529
Tel: 919.772.0115
Fax: 919.772.8259
Email: info@ati-ia.com
http://www.ati-ia.com
BDIGESO 3-03-00
DELTA TRANSDUCER WITH MOUNTING ADAPTOR
1:1
B-11X17
9230-05-1102-02

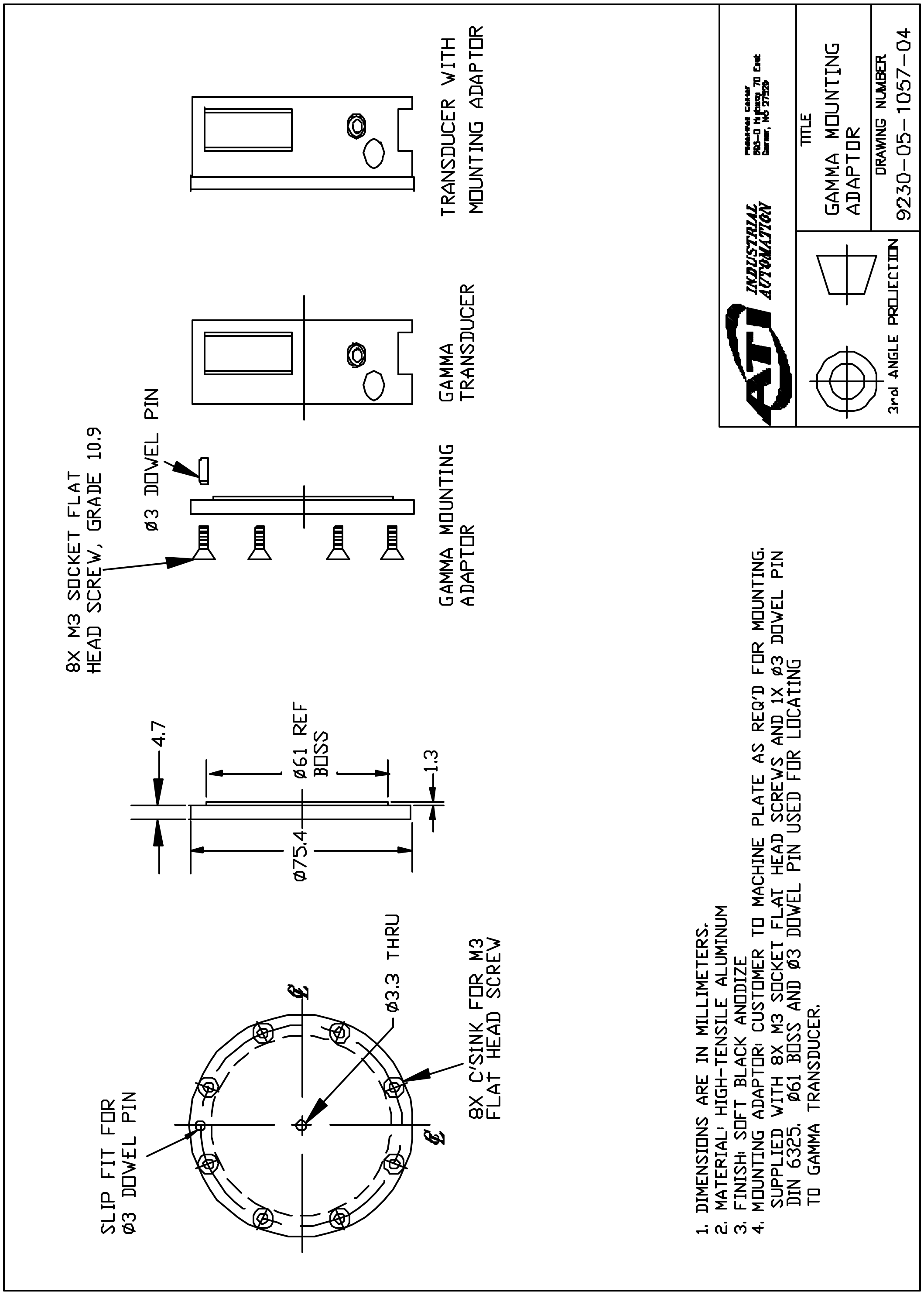

MOUNTING SIDE
SIDE VIEW
TOOL SIDE
ISOMETRIC VIEW
TOOL ADAPTOR
MOUNTING ADAPTOR
MOUNTING ADAPTOR PLATE IS REMOVEABLE FOR MACHINING
CUSTOMER MACHINES THEIR OWN MOUNTING PATTERN IN PLATE
4X M12 x 1.75 ISO-6H, Ø 100 B.C. DO NOT EXCEED 12 MM EQUALLY SPACED
Ø 40 H7 FIT 9.8 DEEP
45° TYP.
22.5° TYP.
61.1
38.6
12
129
155
NOTES:
1. MATERIAL: HARDENED STAINLESS STEEL, MOUNTING ADAPTOR ALUMINUM.
3. DO NOT TOUCH INTERNAL ELECTRONICS OR INSTRUMENTATION THIS COULD DAMAGE TRANSDUCER AND WILL VOID WARRANTY.
THETA TRANSDUCER WITH MOUNTING ADAPTOR PLATE
9230-05-1104-02

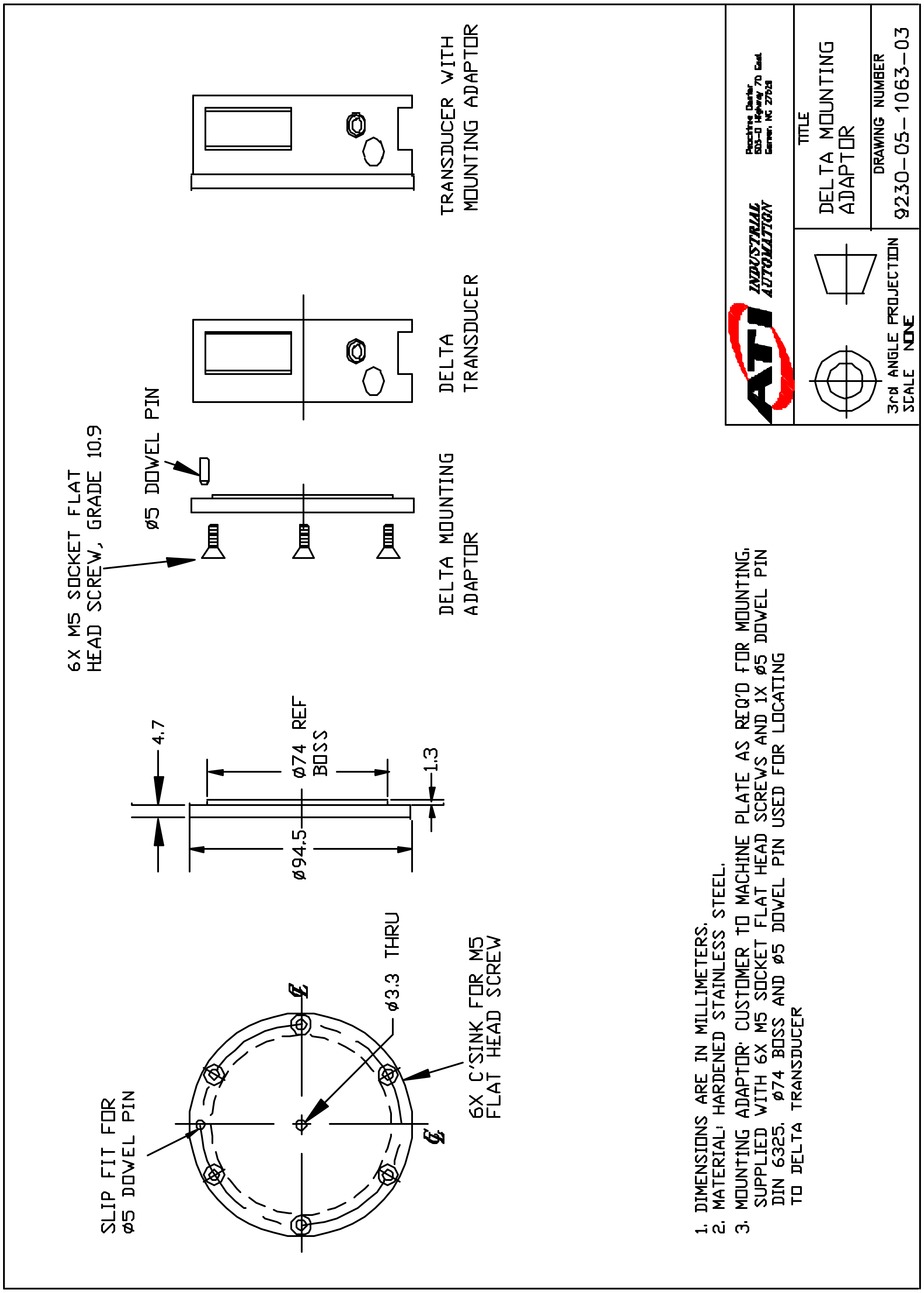


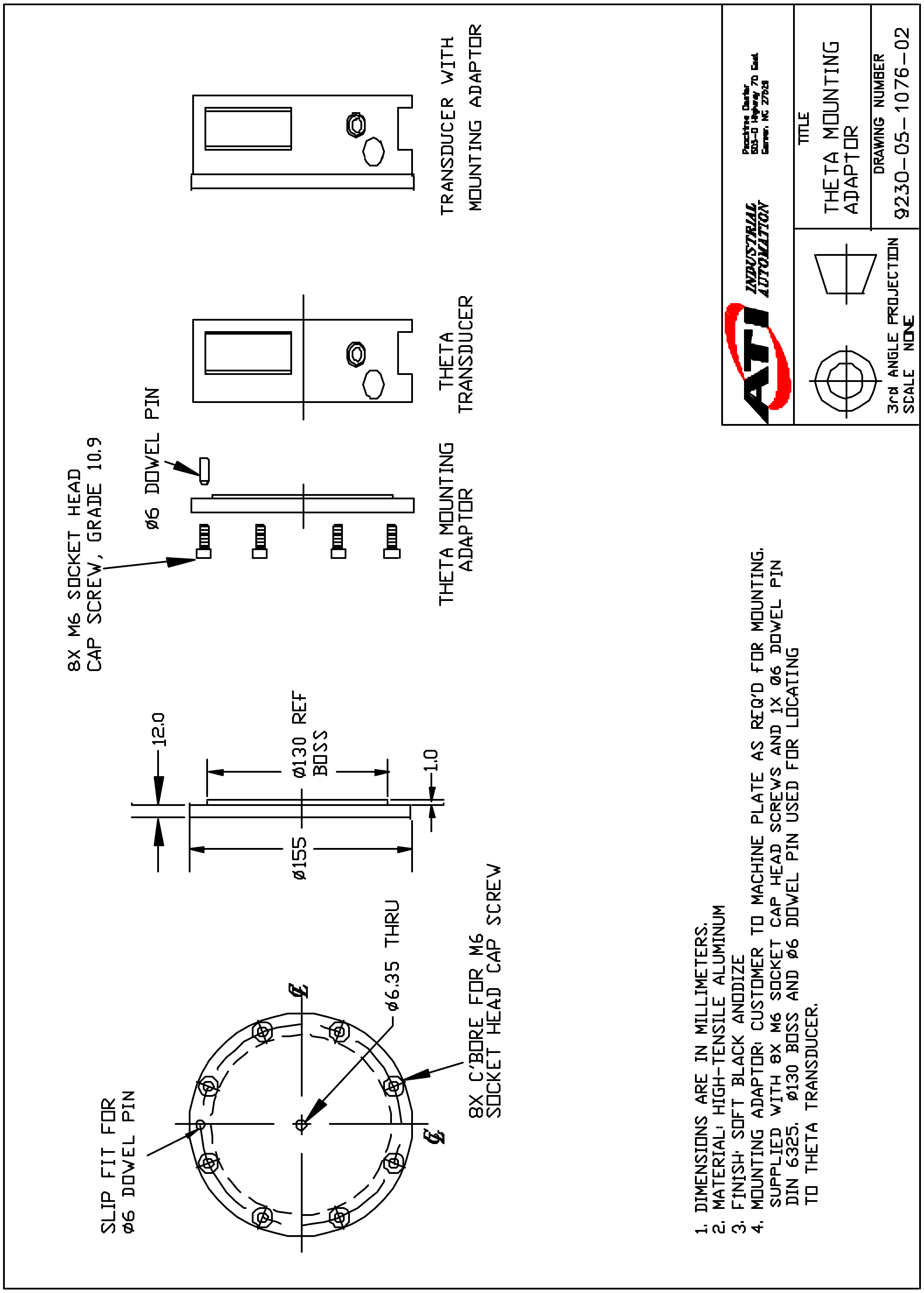
TOOL SIDE
SIDE VIEW
MOUNTING SIDE
ISOMETRIC VIEW
TOOL ADAPTOR
MOUNTING ADAPTOR
RIGHT-ANGLE CONNECTOR
OMEGA160 WITH MOUNTING ADAPTOR PLATE
9230-05-1093-03

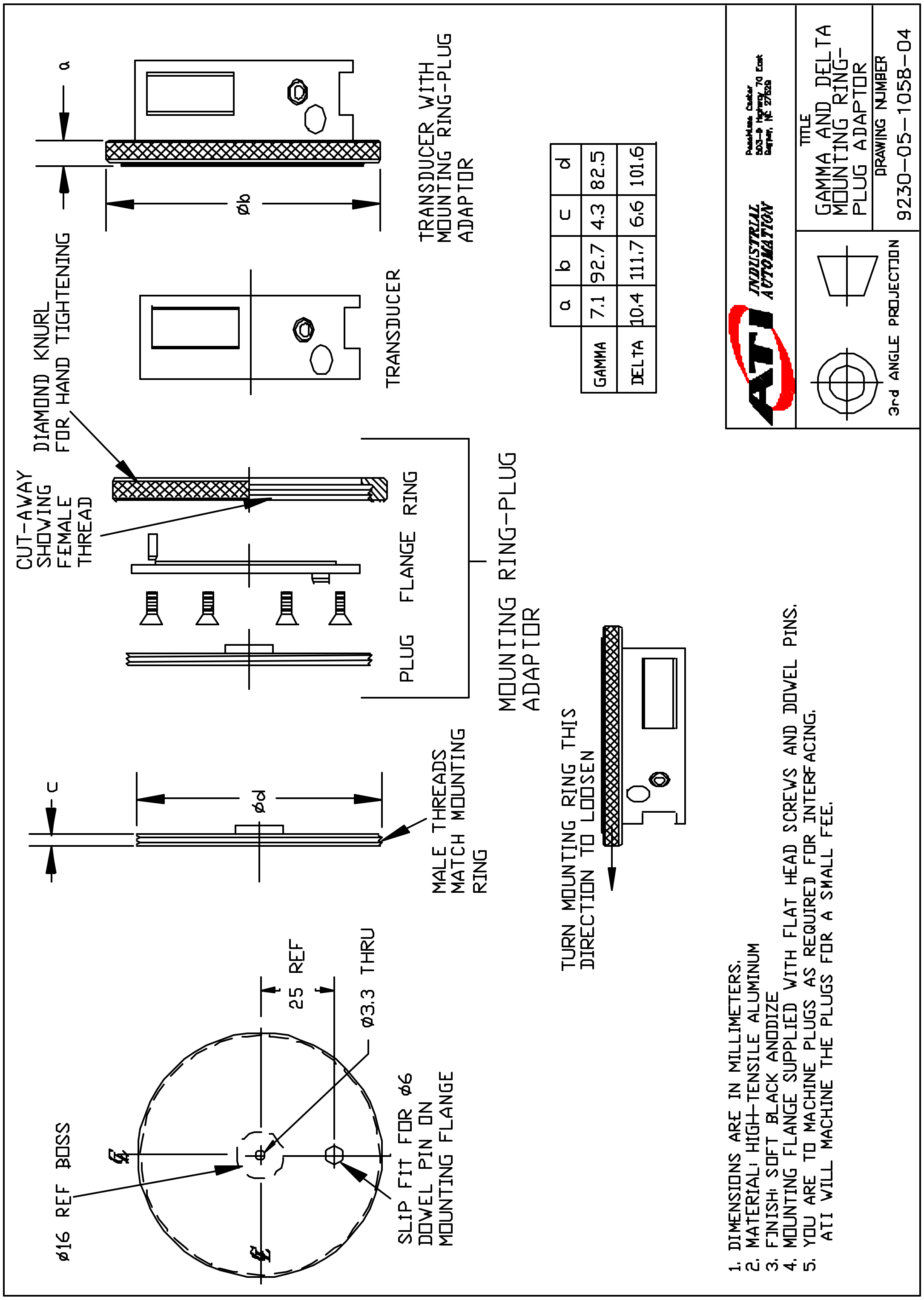


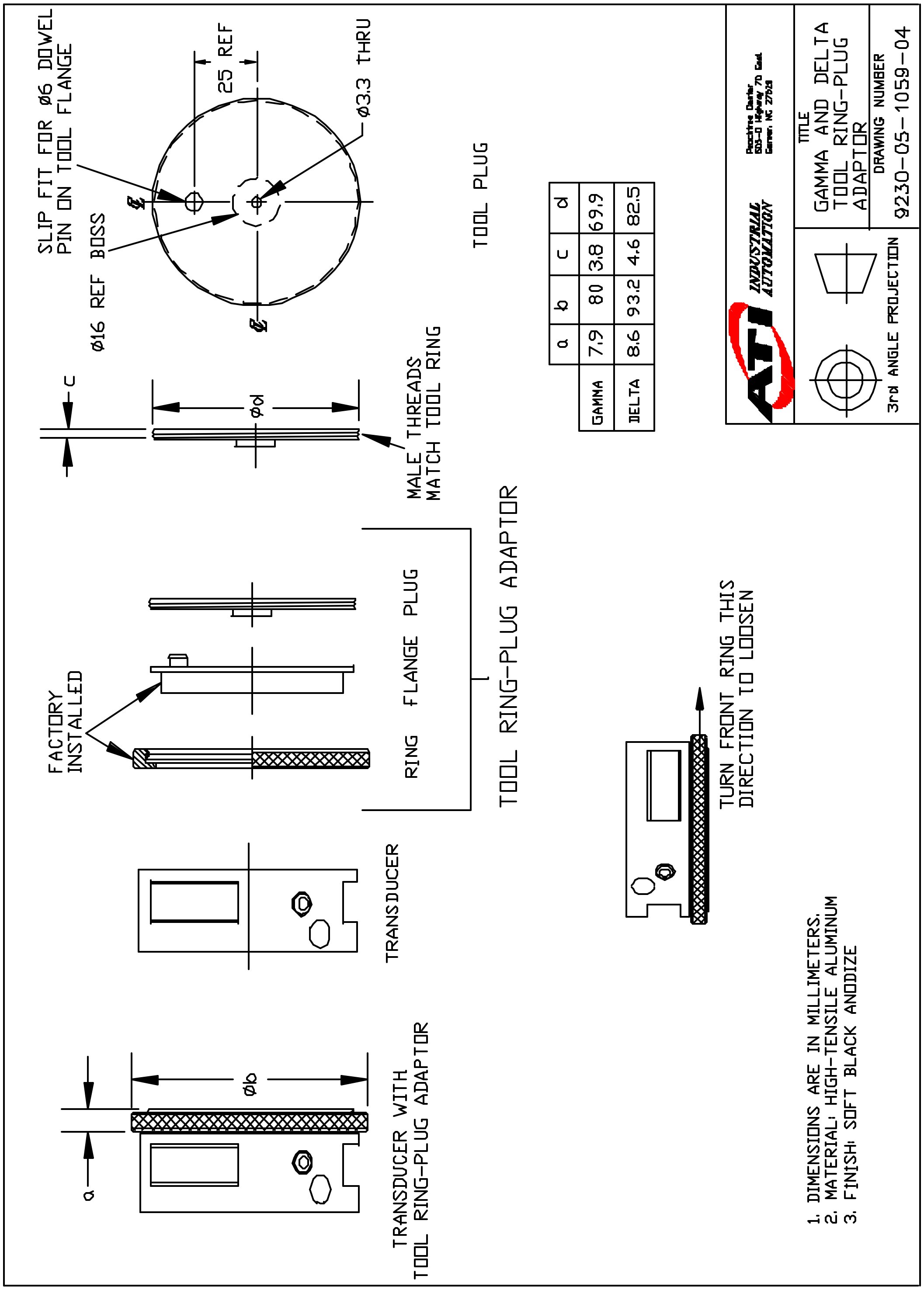
TOOL ADAPTOR
SIDE VIEW
ISOMETRIC VIEW
Tool Plate
Mounting Side
Mounting Adaptor
RIGHT ANGLE CONNECTOR
9X M8 x 25 SOCKET CAP SCREWS Ø175 B.C.
8X M8 x 1.25 ISO-6H B.C. Ø140MM DO NOT EXCEED 8MM DEEP EQUALLY SPACED
6X M12 x 1.75 ISO-6H B.C. Ø 150MM DO NOT EXCEED 15MM DEEP EQUALLY SPACED
NOTES:
1. MATERIAL: HARDENED STAINLESS STEEL AND AIRCRAFT ALUMINUM.
2. SENSING REFERENCE FRAME ORIGIN AT SURFACE CENTER OF TOOL ADAPTOR.
3. DO NOT DISASSEMBLE THIS UNIT. ANY SUCH ACTION WILL VOID WARRANTY.
OMEGA190
9230-05-1095-05

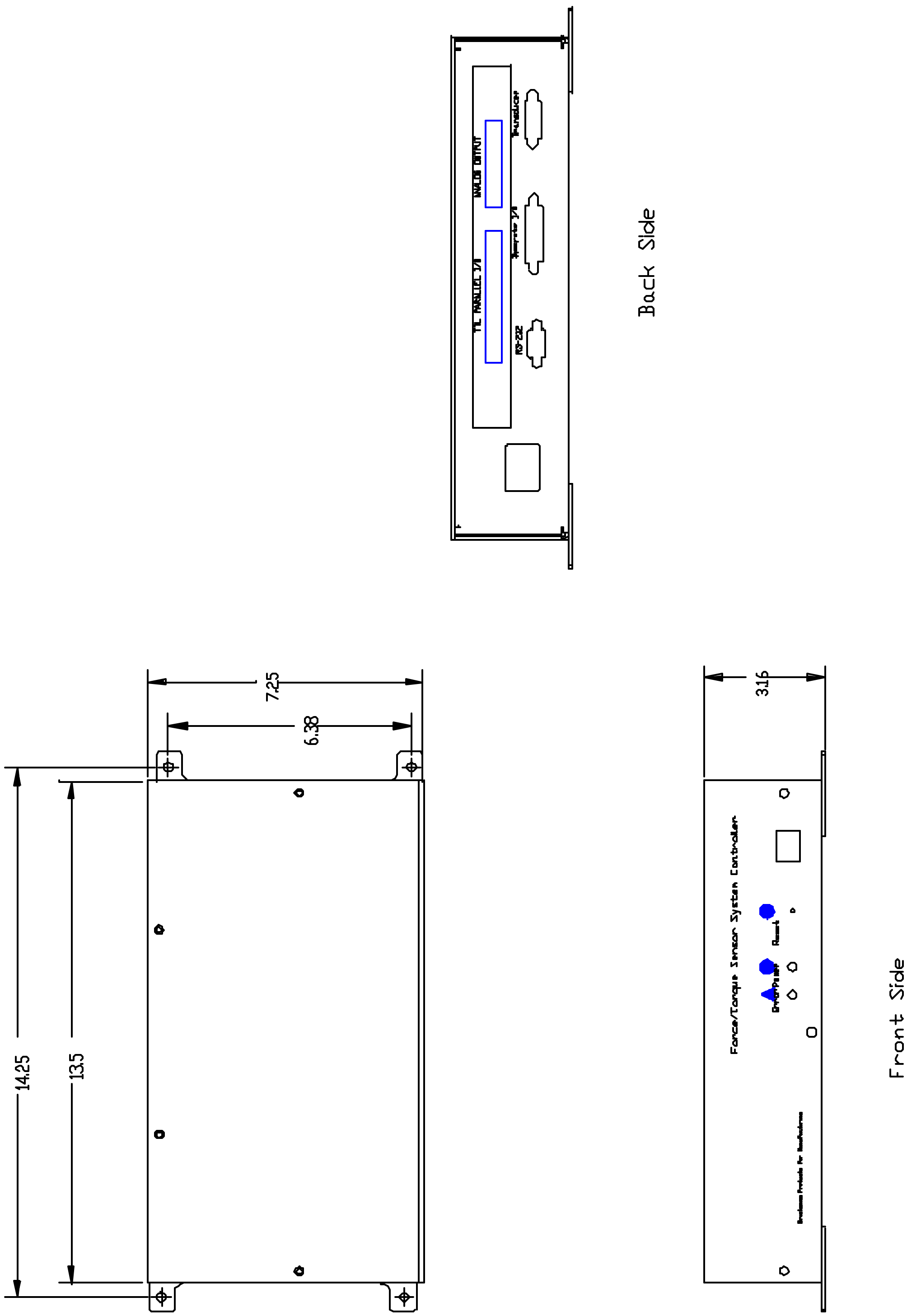

TRANSDUCER WITH
MOUNTING ADAPTOR
GAMMA
TRANSDUCER
GAMMA MOUNTING
ADAPTOR
Ø3 DOWEL PIN
8X M3 SOCKET FLAT
HEAD SCREW, GRADE 10.9
4.7
Ø61 REF
BOSS
1.3
Ø75.4
Ø3.3 THRU
8X C'SINK FOR M3
FLAT HEAD SCREW
SLIP FIT FOR
Ø3 DOWEL PIN
1. DIMENSIONS ARE IN MILLIMETERS.
2. MATERIAL: HIGH-TENSILE ALUMINUM
3. FINISH: SOFT BLACK ANODIZE
4. MOUNTING ADAPTOR: CUSTOMER TO MACHINE PLATE AS REQ'D FOR MOUNTING.
SUPPLIED WITH 8X M3 SOCKET FLAT HEAD SCREWS AND 1X Ø3 DOWEL PIN
DIN 6325. Ø61 BOSS AND Ø3 DOWEL PIN USED FOR LOCATING
TO GAMMA TRANSDUCER.
INDUSTRIAL
AUTOMATION
TITLE
GAMMA MOUNTING
ADAPTOR
DRAWING NUMBER
9230-05-1057-04
3rd ANGLE PROJECTION


SLIP FIT FOR
Ø5 DOWEL PIN
Ø3.3 THRU
6X C'SINK FOR M5
FLAT HEAD SCREW
Ø94.5
Ø74 REF
BOSS
4.7
1.3
6X M5 SOCKET FLAT
HEAD SCREW, GRADE 10.9
Ø5 DOWEL PIN
DELTA MOUNTING
ADAPTOR
DELTA
TRANSDUCER
TRANSDUCER WITH
MOUNTING ADAPTOR
1. DIMENSIONS ARE IN MILLIMETERS.
2. MATERIAL: HARDENED STAINLESS STEEL.
3. MOUNTING ADAPTOR: CUSTOMER TO MACHINE PLATE AS REQ'D FOR MOUNTING.
SUPPLIED WITH 6X M5 SOCKET FLAT HEAD SCREWS AND 1X Ø5 DOWEL PIN
DIN 6325. Ø74 BOSS AND Ø5 DOWEL PIN USED FOR LOCATING
TO DELTA TRANSDUCER
ATI INDUSTRIAL AUTOMATION
TITLE
DELTA MOUNTING
ADAPTOR
DRAWING NUMBER
9230-05-1063-03
3rd ANGLE PROJECTION
SCALE NONE

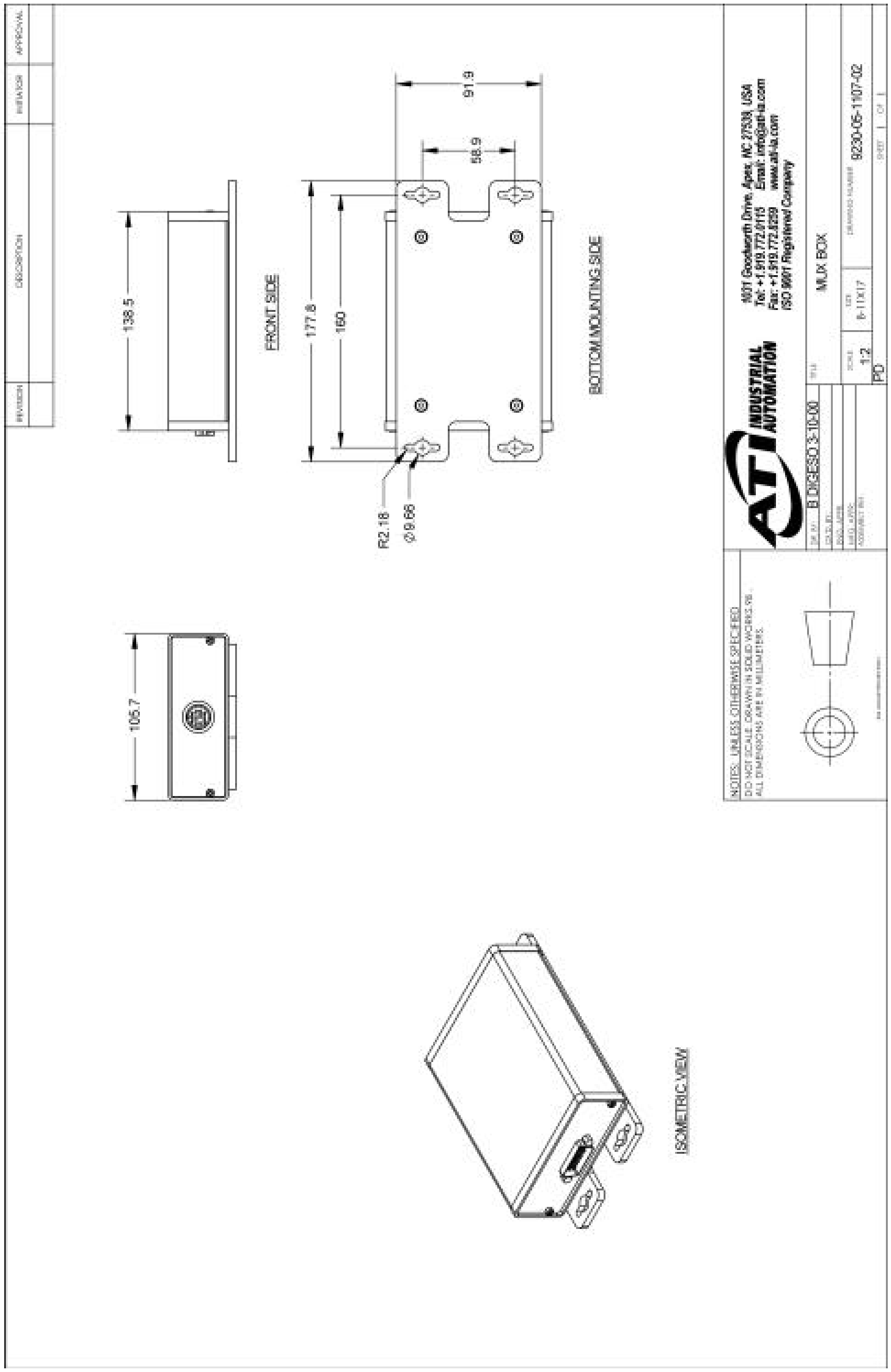

SLIP FIT FOR
Ø6 DOWEL PIN
Ø6.35 THRU
8X C'BORE FOR M6
SOCKET HEAD CAP SCREW
Ø155
12.0
Ø130 REF
BOSS
1.0
8X M6 SOCKET HEAD
CAP SCREW, GRADE 10.9
Ø6 DOWEL PIN
THETA MOUNTING
ADAPTOR
THETA
TRANSDUCER
TRANSDUCER WITH
MOUNTING ADAPTOR
1. DIMENSIONS ARE IN MILLIMETERS.
2. MATERIAL: HIGH-TENSILE ALUMINUM
3. FINISH: SOFT BLACK ANODIZE
4. MOUNTING ADAPTOR: CUSTOMER TO MACHINE PLATE AS REQ'D FOR MOUNTING.
SUPPLIED WITH 8X M6 SOCKET CAP HEAD SCREWS AND 1X Ø6 DOWEL PIN
DIN 6325. Ø130 BOSS AND Ø6 DOWEL PIN USED FOR LOCATING
TO THETA TRANSDUCER.
ATI INDUSTRIAL AUTOMATION
TITLE
THETA MOUNTING
ADAPTOR
DRAWING NUMBER
9230-05-1076-02
3rd ANGLE PROJECTION
SCALE NONE


ø16 REF BOSS
SLIP FIT FOR ø6 DOWEL PIN ON MOUNTING FLANGE
25 REF
ø3.3 THRU
c
ød
MALE THREADS MATCH MOUNTING RING
PLUG
FLANGE
RING
CUT-AWAY SHOWING FEMALE THREAD
DIAMOND KNURL FOR HAND TIGHTENING
MOUNTING RING-PLUG ADAPTOR
TRANSDUCER
a
øb
TRANSDUCER WITH MOUNTING RING-PLUG ADAPTOR
TURN MOUNTING RING THIS DIRECTION TO LOOSEN
	a	b	c	d
GAMMA	7.1	92.7	4.3	82.5
DELTA	10.4	111.7	6.6	101.6
1. DIMENSIONS ARE IN MILLIMETERS.
2. MATERIAL: HIGH-TENSILE ALUMINUM
3. FINISH: SOFT BLACK ANODIZE
4. MOUNTING FLANGE SUPPLIED WITH FLAT HEAD SCREWS AND DOWEL PINS.
5. YOU ARE TO MACHINE PLUGS AS REQUIRED FOR INTERFACING. ATI WILL MACHINE THE PLUGS FOR A SMALL FEE.
ATI INDUSTRIAL AUTOMATION
TITLE
GAMMA AND DELTA MOUNTING RING-PLUG ADAPTOR
DRAWING NUMBER
9230-05-1058-04
3rd ANGLE PROJECTION


SLIP FIT FOR Ø6 DOWEL PIN ON TOOL FLANGE
25 REF
Ø3.3 THRU
Ø16 REF BOSS
TOOL PLUG
c
Ød
MALE THREADS MATCH TOOL RING
FACTORY INSTALLED
RING
FLANGE
PLUG
TOOL RING-PLUG ADAPTOR
TRANSDUCER
TURN FRONT RING THIS DIRECTION TO LOOSEN
a
Øb
TRANSDUCER WITH TOOL RING-PLUG ADAPTOR
	a	b	c	d
GAMMA	7.9	80	3.8	69.9
DELTA	8.6	93.2	4.6	82.5
ATI INDUSTRIAL AUTOMATION
TITLE
GAMMA AND DELTA TOOL RING-PLUG ADAPTOR
DRAWING NUMBER
9230-05-1059-04
3rd ANGLE PROJECTION
1. DIMENSIONS ARE IN MILLIMETERS.
2. MATERIAL: HIGH-TENSILE ALUMINUM
3. FINISH: SOFT BLACK ANODIZE

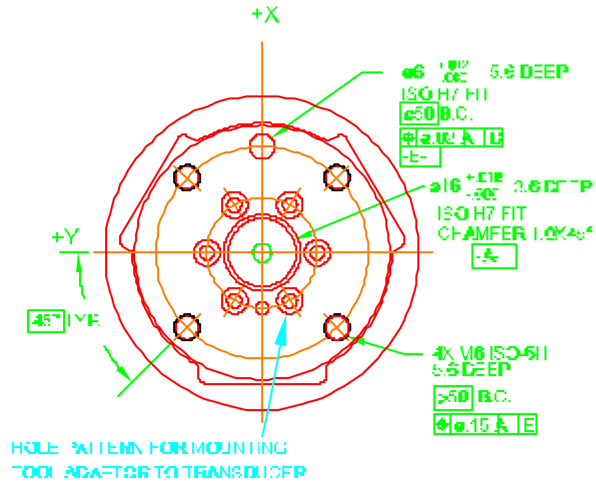


Stand –alone Controller Chassis: Dimensions in Millimeters

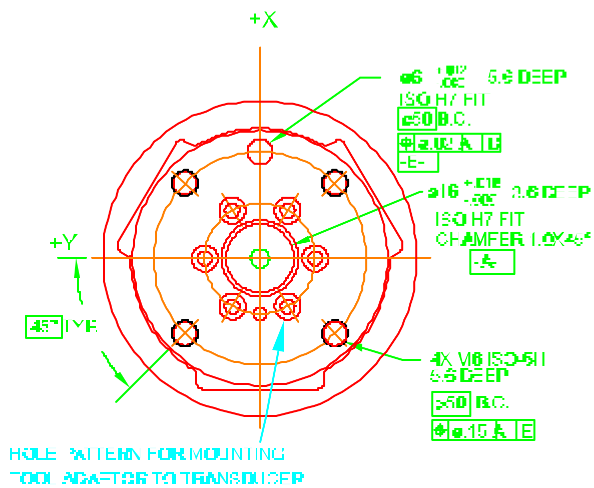

138.5
FRONT SIDE
105.7
91.9
58.9
177.8
160
R2.18
Ø9.66
BOTTOM MOUNTING SIDE
ISOMETRIC VIEW
NOTES: UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN MILLIMETERS
INDUSTRIAL AUTOMATION
1031 Goodworth Drive, Apex, NC 27539, USA
Tel: +1.919.772.0115
Fax: +1.919.772.8259
ISO 9001 Registered Company
MUX BOX
1:2
B-11X17
9230-05-1107-02
PD

C

Calibration Matrix and Additional Information



D



Dual Gain Calibration Instructions

F/T Sensors having a Stand-alone Controller with Dual Gain Calibration

The dual gain calibration option offers two calibrations with one F/T sensor system. You can use the same F/T sensor system with a low payload and a high resolution, then switch to a higher payload calibration with a lower resolution. This is done by selecting the desired calibration matrix in the stand-alone controller, then changing the manually operated switch on the mux box to the corresponding calibration.

First, you will need to set up communication with the Stand-alone controller as described Chapter 1. The controller will be set up at the factory having both calibrations loaded into the controller. Normally, the factory default lower payload / higher resolution calibration will be in Tool Frame 0 and the higher payload / lower resolution calibration will be in Tool Frame 1.

See Chapter 4, Section 4.6 Tool Frame Commands for help with selecting the Tool Frame. For this Dual Gain example let's imagine we have a Theta model sensor having both a FT1122 US-200-1000 calibration in Tool Frame 0 and a FT2211 US-600-3600 calibration in Tool Frame 1. This example starts with the lower payload FT1122 calibration currently selected and with the header message shown. You will enter the commands shown in **bold** to select the higher calibration.

```
F200/T1000(8/4)   SN FT1122-3F   Version  5.00
Copyright(c) 1990 - 1994 by Assurance Technologies, Inc.,
Garner, NC
All Rights Reserved
>TL
 0) FT1122,     0,     0,     0,     0,     0,     0
 1) FT2211,     0,     0,     0,     0,     0,     0
 2)       ,     0,     0,     0,     0,     0,     0
 3)       ,     0,     0,     0,     0,     0,     0
>TF1       ( Press enter to select Tool Frame 1, the larger calibration)
>RS        ( Press enter to store TF 1 in permanent memory)
> Ctrl-W   ( To reset the system and see the selected tool frame)

F600/T3600(2/1)   SN FT2211-3F   Version  5.00
Copyright(c) 1990 - 1994 by Assurance Technologies, Inc.,
Garner, NC
All Rights Reserved
```

Now change the manually-operated switch, located on the mux box, to match the current calibration serial number loaded into the controller. This can be done with the controllers power on and no damage will occur. Use this procedure to switch between the calibration and the F/T sensor will give accurate data.

> ⚠ **Warning... If the serial numbers do not match, the Force and Torque data will be incorrect.**