Monitor with Confidence

MEMS In-Place Inclinometer System

Instruction Manual

Document Number: ICM0062K

Release Date: 15-May-2023

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REVISION HISTORY

Rev.	Revision History	Date	Prepared By	Approved By
J	Content updated for IC27050, revision table added.	2020-Sep-17	MP	AB
K	Replaced sample calibration chart, added note on p.10 about silicone grease on the connectors.	2023-Apr-28	Ariel V., MP	EG, AV

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1 General Description

RST's MEMS In-Place Inclinometer (IPI) System is designed to reliably measure lateral movement in and around dams, embankments, landfills, landslides, piles, piers, retaining walls, and abutments, particularly when continuous remote monitoring is required. It provides and early warning for movement, essential for protecting life and equipment.

Each IPI employs MEMS accelerometer sensors housed inside a 28.6 mm (1.125 in) diameter, watertight, stainless steel enclosure. The sensor body is rigidly connected to a 25.4 mm (1 in) diameter bay rod, which establishes the length of the IPI. Multiple IPIs are assembled with pivots, allowing for displacement sensing over discreet, configurable intervals. Wheel assemblies centralize the pivot point and establish the azimuth of each IPI. Units are available in sizes to fit 70 mm (2.75 in) or 85 mm (3.34 in) OD inclinometer casings.

The sensors are read through a bussed signal cable designed to chain together multiple sensors. A data logger is used to monitor the deflection of each sensor on the digital bus. If necessary, an alarm can be triggered when movement reaches a designated threshold rate or magnitude.

2 Installation of Standard IPI

2.1 Required Materials and Tools

Before beginning the installation, ensure that the following components and tools are present:

- Correct number and length of IPI bay rods,
- Correct number of IPI sensors with correct cable length,
- Shoulder bolts (2 per bay),
- 3/8" hex wrench,
- Electrical tape,
- Safety cable assembly: Safety cable, clevis pin, locking hair pin, flat washer, D-ring,
- Collar hanger,
- Cross rod (approximately ½" diameter),
- Heavy Over-hole Suspension System (HOSS) (optional), and
- Cable bottom plug.

2.2 INSTALLATION

The following instructions detail the steps required to correctly install a MEMS IPI (Figure 2-1):

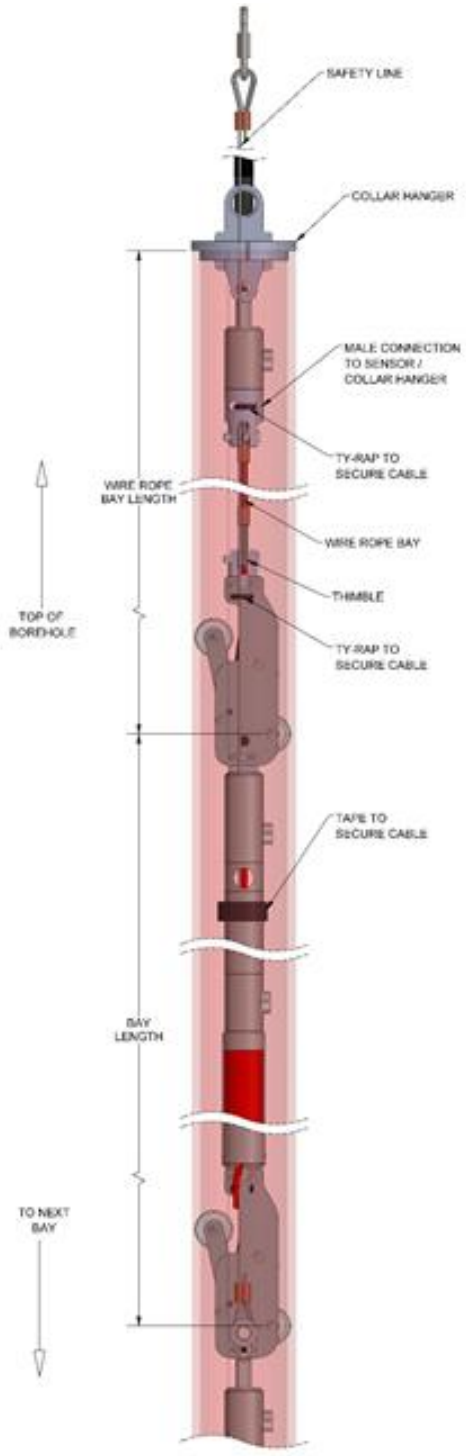


FIGURE 2-1 INSTALLATION OF MEMS IPI

1 Gather the IPI bay rods and sensors.

2 Secure the collar hanger to the top sensor (Figure 2-2). Loosen the shoulder bolt at the top of the IPI sensor and slide the sensor into the collar hanger, aligning the shoulder bolt in the j-slot. Twist the sensor counterclockwise into the seat of the j-slot and tighten the bolt.

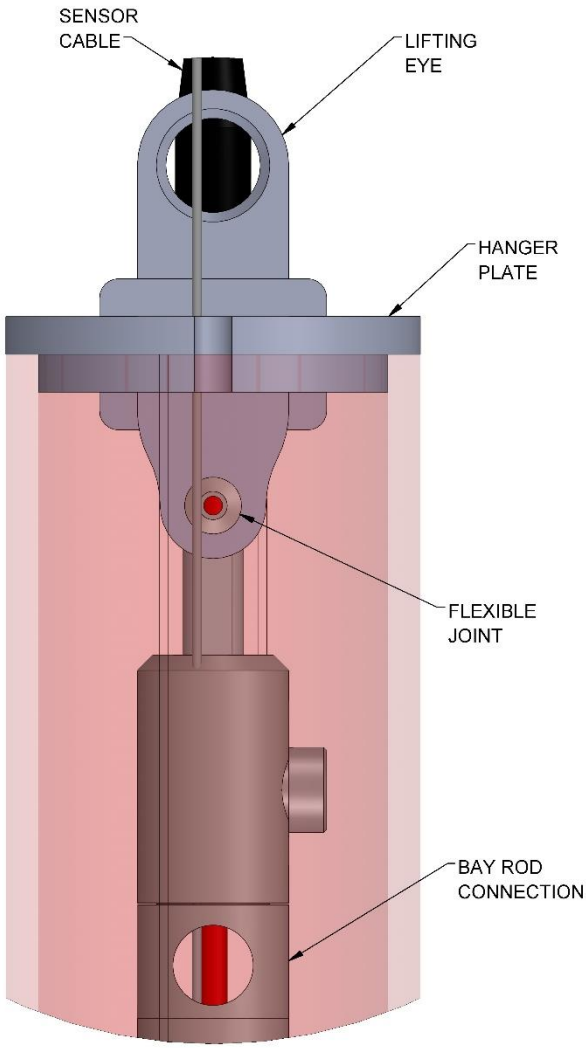


FIGURE 2-2 COLLAR HANGAR SECURED TO TOP SENSOR

3 Loosen the shoulder bolt at the top of the IPI sensor. Slide the bay rod onto the sensor, aligning the shoulder bolt in the j-slot (Figure 2-3, a). Twist the sensor counterclockwise (Figure 2-3, b) into the seat of the j-slot and tighten the bolt (Figure 2-3, c).

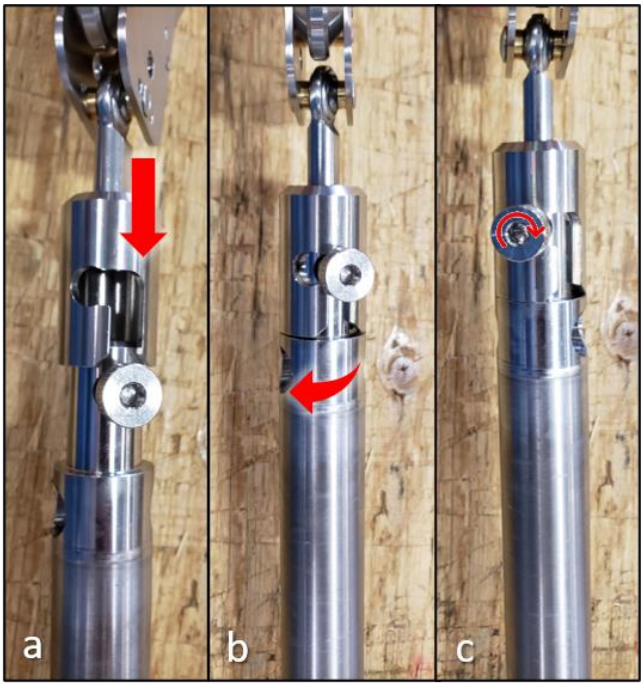


FIGURE 2-3 ATTACHING THE BAY ROD

4 Secure one bay rod to each of the remaining sensors, following the instructions outlined in Step 3.

5 Lay sensor and bay rod assemblies in order of installation from the bottom of the borehole to the top. Record the serial number and position of each sensor.

6 Attach a safety line to the bottom wheel assembly:

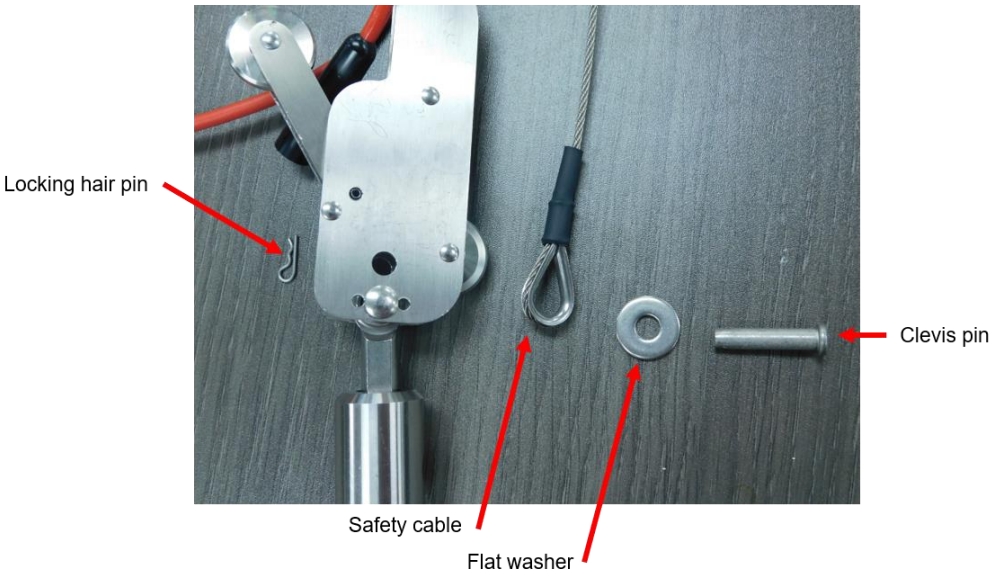
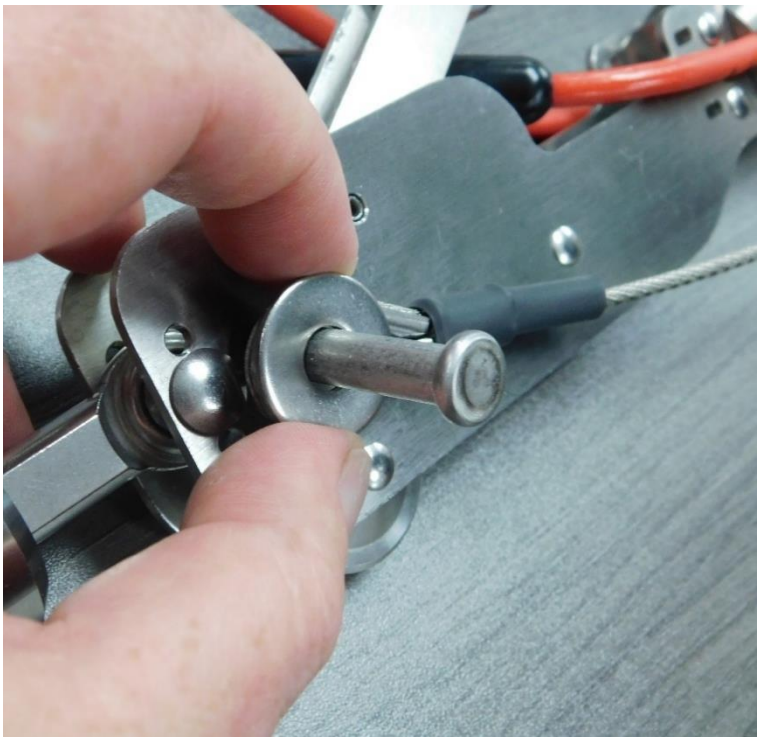


FIGURE 2-4 SAFETY CABLE AND HARDWARE

a Place one end of the safety cable flat against the bottom wheel assembly (Figure 2-5).

FIGURE 2-5 PLACE SAFETY CABLE AGAINST BOTTOM WHEEL ASSEMBLY

b Place a washer on top of the thimble on the safety cable and insert the clevis pin through the washer, cable, and wheel assembly (Figure 2-6).



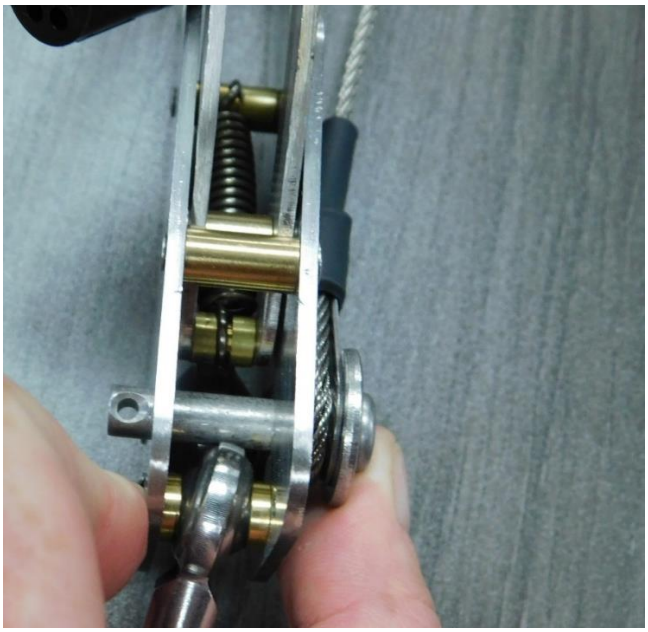


FIGURE 2-6 PLACE WASHER AND INSERT CLEVIS PIN THROUGH WHEEL ASSEMBLY

c Secure the clevis pin on the opposite side of the wheel assembly by inserting the hair pin through the clevis pin (Figure 2-7).

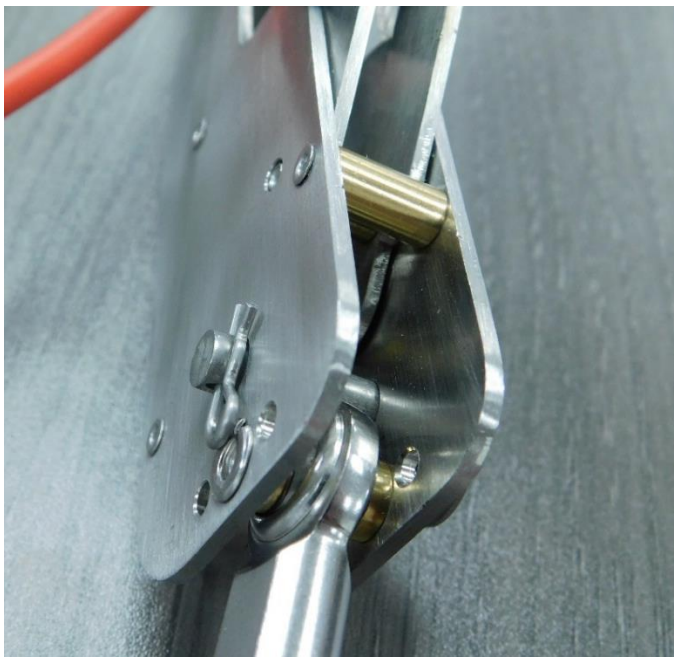


FIGURE 2-7 SECURE CLEVIS PIN WITH LOCKING HAIR PIN

NOTE: Securing the safety link to a winch will maximize control and safety during deep installations. Contact RST for further details.

7 Place the bottom plug onto the bottom sensor cable.

8 Align the A-Axis wheels with the anticipated failure direction. Insert the wheels in the inclinometer casing grooves. The A+ (sprung wheel) should be oriented towards the anticipated movement, as illustrated on the unit's decal. Refer to Figure 2-8.

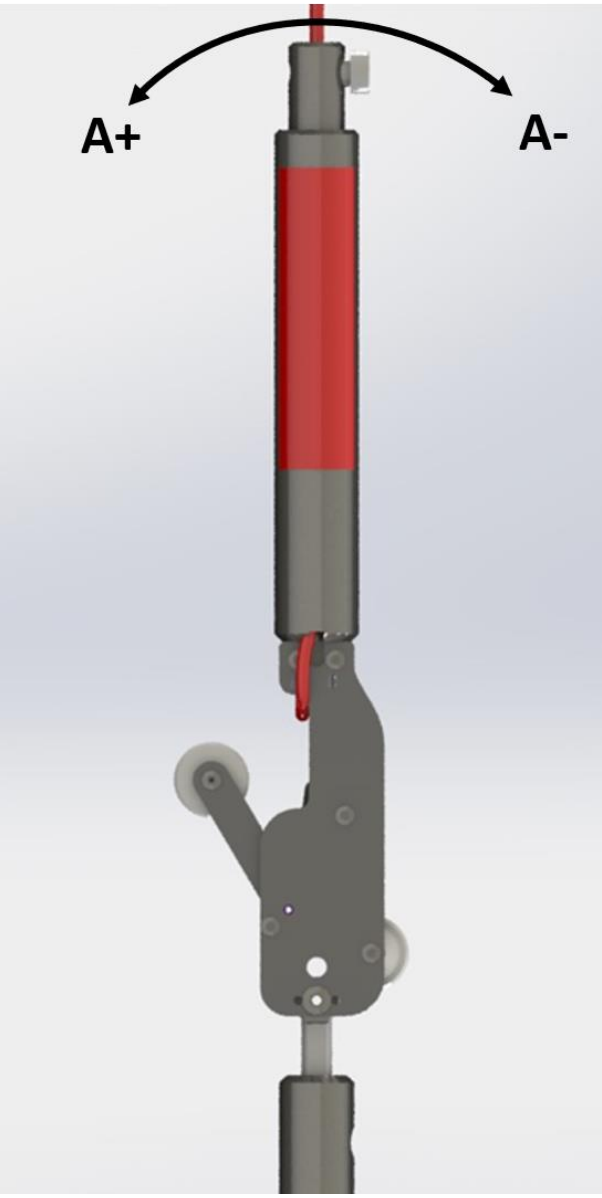


FIGURE 2-8 MEMS IPI AXIS ORIENTATION

9 Slowly lower the bay assembly into the inclinometer casing, taking care not to twist the wheels out of the grooves. Ensure that the signal cable and safety cable do not obstruct the wheels by securing the cables with Ty-rap and tape, as illustrated in Figure 2-1.

10 Secure the IPI from falling downhole by threading the cross rod through the cross hole. If using a HOSS, the winch may also be used to secure the assembly.

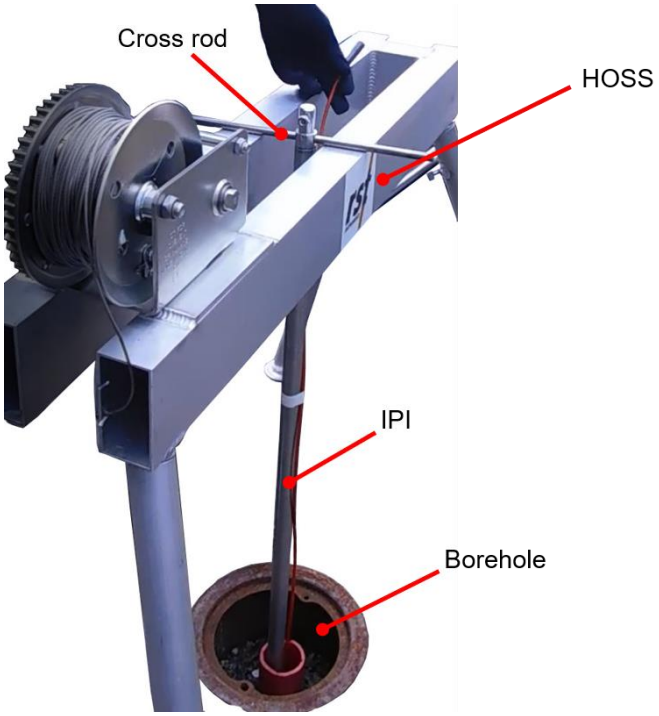


FIGURE 2-9 CROSS ROD AND HOSS

11 Attach the next section of the assembly using a shoulder bolt, as described in Step 3.

12 Attach the connectors. Wrap a length of tape around the connection to prevent dirt and water ingress. Secure the cable to the lower sensor assembly with tape.

NOTE: The cables should be secured in a neat and orderly fashion to prevent the cables from crossing or obstructing the wheel assemblies.

13 Repeat Steps 9 to 12 for the remaining sensor and bay rod assemblies.

14 Connect the top cable to the top sensor and secure with tape.

15 Insert the collar hanger into the casing, ensuring that the cable exits are aligned with the B-axis grooves of the inclinometer casing. Secure the safety cable.

16 Connect the signal cable to a datalogger or readout. See Section 2.4 for connection details.

2.3 STAINLESS STEEL WIRE ROPE INTERVAL

A stainless-steel wire rope interval may be used in place of a bay rod for cases where specific zones are of interest rather than the entire profile of the borehole.

The wire rope interval takes the place of a sensor bay in the IPI chain. The sensor assembly below the wire rope bay is terminated using a top wheel assembly. The top wheel assembly uses a clevis pin with hair pin locker to secure the wire rope section. The wire rope transitions back to the next sensor assembly or collar hanger using a wireline-to-bay adapter.

Installation is the same as the standard IPI installation with respect to orientation and positioning.

The device is secured with the same clevis and hair pin mechanism as the upper wheel assembly.

The wireline bay adapter includes through holes for insertion of a Ty-Rap to relieve strain on the suspended signal cable.

2.4 SIGNAL CABLE AND CONNECTORS

RST IPIs connectors are waterproof and are designed to be submerged (IP68, 2 MPa). The connectors must be kept clean and connected only when clean.

Connectors consist of a plug and receptacle. To successfully make a connection, insert the plug into the receptacle and push until fully inserted.

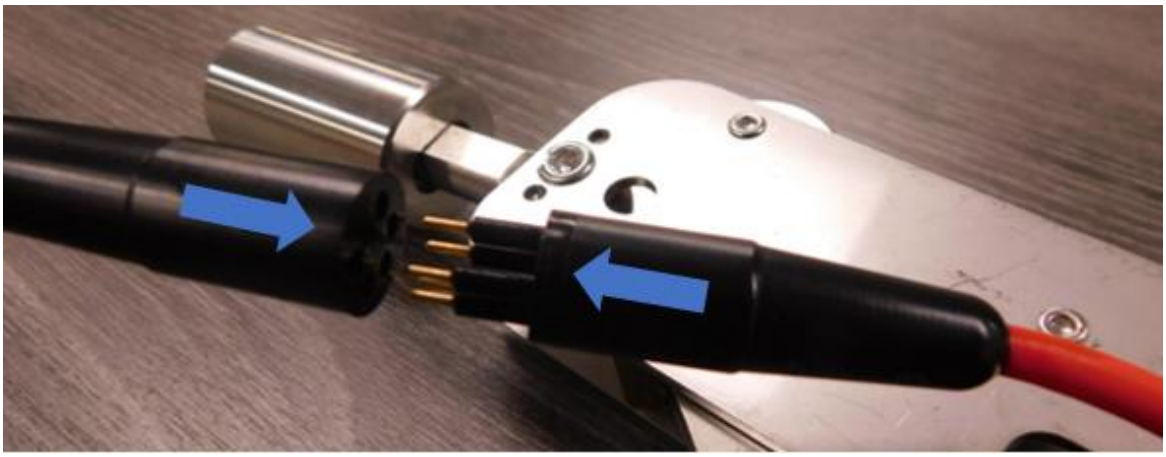


FIGURE 2-10 IPI27050 CONNECTORS

CAUTION: Do not twist the connectors.

NOTE: If the connectors are difficult to connect and disconnect, apply a trace amount of silicone-based lubricant to the mating face of the plug connector.

2.5 CLEANING CONNECTORS

It is strongly recommended to keep caps on connectors until mated to the next sensor to prevent contamination. Store the caps in a clean, dry location for future use.

To prevent potential contamination, cover the IPI connectors with the provided connector caps each time the IPI is disassembled (Figure 2-11). Ensure that protective caps are always on the connectors when the connector are not in use.

Any dirt within the connectors may cause water ingress and cause an entire string of IPIs to fail.

CAUTION: Contamination, such as dirt or dust, in the connectors can cause read failures in an entire string of IPIs.

In the event of contamination within the connectors, the connector ends may be flushed with isopropyl alcohol and set aside to dry.

FIGURE 2-11 ENSURE THE PROTECTIVE CAPS ARE PLACED ON THE CONNECTORS WHEN NOT IN USE

2.6 DIGITAL OUTPUT FOR MEMS IPI SYSTEM

TABLE 2-1 DIGITAL OUTPUT FOR MEMS IPI SYSTEM

Wire Color	MEMS IPI
Red	V +
Black	GND
Green	RS485 A-
White	RS485 B+

2.7 REINSTALLATION

IPIs may be reused for different sites. In the case of removing a previously installed IPI and reinstalling elsewhere, ensure the IPI, especially the connectors, remain clean. Refer to Section 2.5 for instructions on cleaning the IPI connectors. Dirt can be removed from the instrument itself with clean water and a damp cloth.

Always keep the connector caps on when the inclinometers are not in use. Always clean the connectors after detaching the IPIs. Ensure the IPIs and connectors are clean and dry before reinstallation.

3 MEMS HORIZONTAL IPI DETAILS

The RST MEMS Horizontal In-Place Inclinometer is installed and measures deflection horizontally as opposed to vertically. Construction and electronics are the same as the vertical IPI probes outlined above.

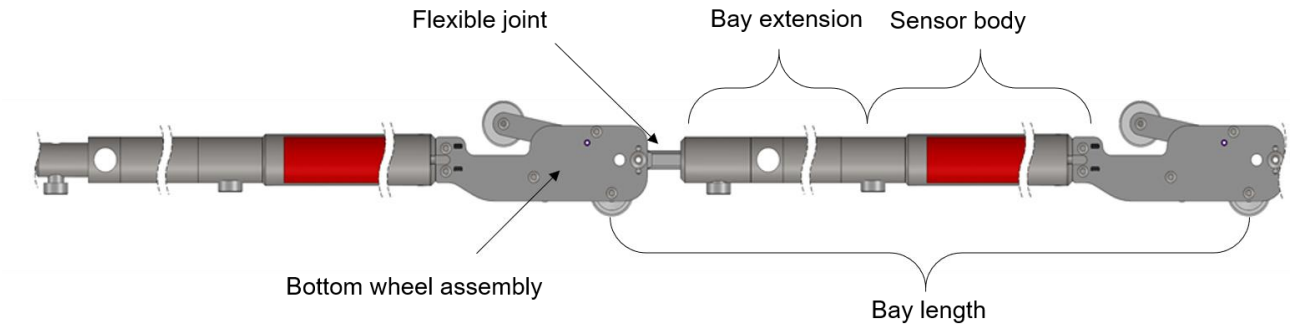


FIGURE 3-1 MEMS HORIZONTAL IPI ORIENTATION

3.1 INSTALLATION

The following steps detail the procedure for installing a horizontal IPI.

Place the sprung wheel upwards in the inclinometer casing for correct orientation, as illustrated in Figure 3-1.

1 Follow the assembly instructions in Section 2.2, steps 1 to 5.

2 Place a bottom cable plug onto the bottom sensor cable.

3 Insert the bottom sensor and bay rod assembly into the borehole with the wheels in the inclinometer casing grooves and the sprung wheel facing up (this aligns the A-Axis wheels with the anticipated failure direction). Secure in place.

NOTE: Place the sprung wheel facing upwards in the inclinometer casing for correct orientation.

4 Loosen the shoulder bolt at the top of the installed IPI sensor. Slide the next bay rod and sensor assembly onto the installed sensor, aligning the shoulder bolt in the j-slot. Twist the sensor counterclockwise into the seat of the j-slot and tighten the bolt.

5 Attach the connectors. Wrap a length of length tape around the connection to prevent dirt and water ingress. Secure the cable from the lower sensor assembly with tape.

6 Repeat steps 3 – 5 for the remaining sensor and bay rod assemblies, including the top bay rod and sensor assembly.

7 Secure the hanger plate to the top sensor (Figure 2-2). Loosen the shoulder bolt at the top of the IPI sensor and slide the sensor into the collar hanger, aligning the shoulder bolt in the j-slot. Twist the sensor counterclockwise into the seat of the j-slot and tighten the bolt. Insert into the casing until the hanger plate sockets inside the top of the casing.

4 OPERATION

The MEMS In-Place Inclinometers measure tilt in two planes with two MEMS accelerometers arranged at 90°. Both axes are calibrated across a ±30° range.

4.1 INITIAL READINGS

Since IPIs are relative movement devices, it is critical to record initial readings. RST recommends surveying the inclinometer with the RST Digital Inclinometer System prior to installing the IPI. Contact RST for further information.

For each IPI sensor on the string, record measurements for tilt in the A axis, tilt in the B axis, and temperature.

4.2 CALCULATIONS

IPIs are relative measurement devices. To calculate the displacement of the instrument over time, the initial tilt reading is subtracted from the current tilt reading and multiplied by the gauge length.

The device output is reported in sine of the angle from vertical (tilt), using the following equation:

EQUATION 4-1 TILT DISPLACEMENT OVER TIME

$$\boldsymbol{d = L(\sin(\theta) - \sin(\theta_i))}$$

$where$:

$d = displacement$

$L = gauge\ length$

$\sin(\theta) = current\ device\ output$

$\sin(\theta_i) = initial\ device\ output$

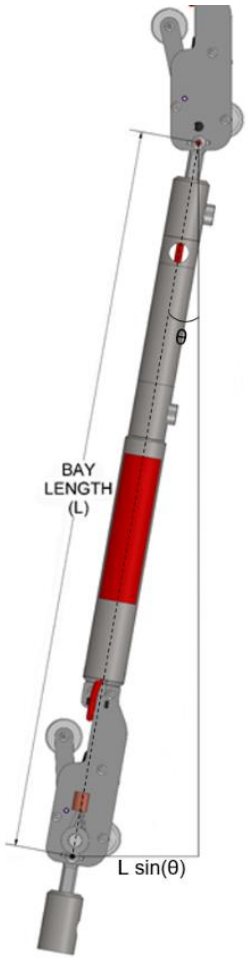


FIGURE 4-1 MEMS IPI REACTION

5 SENSOR SPECIFICATIONS

TABLE 5-1 SENSOR SPECIFICATIONS

Item	Specification
Sensor	
Range	±30°
Resolution	0.0002° (0.004 mm/m)
Non-linearity	±0.002° (0.03 mm/m)
Precision	±0.0013° (0.02 mm/m) (99% Confidence Interval)
Sensor	MEMS Accelerometer
Temperature Offset Uncertainty	±0.0002°/°C
Sensor Temperature Sensitivity	±0.01% of reading/°C
Temperature Accuracy	±0.05°C (0°C to 60°C) ±1.0°C (0°C to 60°C)
Temperature Resolution	±0.06°C
Electrical	
Supply Voltage	5 to 15V DC
Operating Current	490 µA (Reading Average, per sensor)
Standby Current	<20 µA (per sensor)
Signal Output	RS485 Digital Bus (MODBUS RTU Protocol)
Operating Temperature	-40 to 60°C (-40 to 140°F)
Mechanical	
Ingress Protection	IP68 (2 MPa)
Gauge Length	0.5 – 3 m
Sensor Diameter	28.6 mm (1.125 in)
Bay Rod Diameter	25.4 mm (1.0 in)
Wheel Assembly	70 mm (2.75 in) 85 mm (3.34 in)
System Maximum Weight	180 kgf
Sensor and Bay Rod Assembly Weight (Dry, submerged H_2O)	0.5 m: 1.25, 1.00 kgf 1.0 m: 1.63, 1.12 kgf 1.5 m: 2.00, 1.24 kgf 2.0 m: 2.37, 1.36 kgf 3.0 m: 3.11, 1.60 kgf

6 SERVICE, REPAIR AND CONTACT INFORMATION

This product does not contain any user-serviceable parts Contact RST for product services or repairs.

- For sales information: sales@rstinstruments.com
- For technical support: support@rstinstruments.com
- Website: www.rstinstruments.com
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Appendix A SAMPLE CALIBRATION CERTIFICATE FOR DIGITAL OUTPUT MEMS IPI

Monitor with Confidence

Calibration Record

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e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

MEMS Biaxial In-Place Inclinometer - Digital Bus Output

Serial Number: BI0000083891
Calibration Date: April 7, 2021
Inclinometer Frame: RST07
Referenced to National Standards Annually

Wiring

Colour	Function	Pin
Red	Voltage +	1
Black	Ground	2
Green	RS485 A+	3
White	RS485 B-	4
Bare	Shield	5

A-Axis

Applied Degrees	Applied Sin	Displayed Sin	Error Sin
-30	-0.50000	-0.50000	0.00000
-25	-0.42262	-0.42262	0.00000
-20	-0.34202	-0.34201	0.00001
-15	-0.25882	-0.25881	0.00001
-10	-0.17365	-0.17364	0.00001
-5	-0.08716	-0.08714	0.00001
0	0.00000	0.00000	0.00000
5	0.08716	0.08715	0.00000
10	0.17365	0.17364	0.00001
15	0.25882	0.25882	0.00000
20	0.34202	0.34202	0.00000
25	0.42262	0.42263	0.00001
30	0.50000	0.50000	0.00000

B-Axis

Applied Degrees	Applied Sin	Displayed Sin	Error Sin
-30	-0.50000	-0.49998	0.00002
-25	-0.42262	-0.42260	0.00002
-20	-0.34202	-0.34199	0.00003
-15	-0.25882	-0.25880	0.00002
-10	-0.17365	-0.17364	0.00001
-5	-0.08716	-0.08716	0.00000
0	0.00000	-0.00000	0.00000
5	0.08716	0.08715	0.00001
10	0.17365	0.17364	0.00001
15	0.25882	0.25881	0.00001
20	0.34202	0.34201	0.00001
25	0.42262	0.42261	0.00001
30	0.50000	0.50000	0.00000

Calibrated By: HB **Date:** 07/04/2021
Checked By: Sa[redacted]iani **Date:** 21/04/2021

This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1