Michigan Scientific Corporation
Wheel Load Measurement System

Model: LW9.5 and LW9.5T

For ATV's and Small Vehicles

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Introduction

The Michigan Scientific Wheel Load Transducer system is a 6-axes transducer that measures forces and moments on a vehicle wheel. It offers quick setup and accurate measurement of force and moment inputs on a vehicle hub.

The sensor mounts between the tire and vehicle hub. A modified wheel rim is used to adapt to the vehicles tire, and a hub adapter is used to mount it to the vehicle spindle. All forces and moments on the wheel must pass through the sensor before being transferred to the vehicle hub.

Six independent strain gage bridges measure the forces and moments. The sensor is designed to have low cross talk between channels and to be insensitive to temperature change and magnetic fields. Signal conditioning is mounted close by the sensor to boost the signal from the rotating side of the slip ring.

A 20-circuit slip ring with a 512-pulse optical encoder transfers signals to the stationary side. The encoder provides angular position that used for calculating wheel velocity and transforming data from wheel to vehicle coordinates.

The sensor measures the forces and moments in a spinning coordinate system. Therefore as the wheel rotates, the output from the radial channels change. The sensor uses SAE coordinates: where the x-axis is straight ahead, the y-axis is to the right and the z-axis is straight down. The output from the x and z-axes will look like a sine and cosine wave as the wheel turns. In most applications this data must be transformed to vehicle coordinates before it is usable.

Coordinate transformation and the user interface is handled by the Load Wheel Interface electronics. A zero procedure automates the sensor-offset adjustment. Options allow the sensor to be used in both rotating or non-rotation modes and control bridge excitation. The user selects which side of the vehicle the sensor is placed and corrections will be made to keep the output in SAE coordinates. Error checking is in place to alert the user if the system is out of tolerance. Corrections are made for cross axis sensitivity. Finally, a shunt procedure calculates output sensitivities and allows the user to record shunt values.

These features are discussed on the following pages:

Specifications

MSCLW9.5
6-Axis Wheel Load Sensor
Stainless Steel

Maximum Force Capacity	[Fx, Fz]	8,000 lb	35.6 kN
	[Fy] at Tire Patch	4,000 lb	17.8 kN
Maximum Torque Capacity	[Mx, My, Mz]	4,000 lb-ft	5.4 kN-m
Maximum Measurable Capacity	[Fx, Fz]	6,500 lb	28.9 kN
	[Fy] at Tire Patch	4,000 lb	17.8 kN
	[Mx, My, Mz]	4,000 lb-ft	5.4 kN-m

Full Scale Output (before amplifier)	1mV/V nominal
Sensor	4 arm strain gage bridges
Nonlinearity	Less than 1% of full-scale output
Hysteresis	Less than 1% of full-scale output
Repeatability	Less than 1% of full-scale output
Zero Balance prior to installation	Less than 2% of rated output
Cross Axis Sensitivity	<2% of full-scale
Radial Sensitivity Variation	<.5% of radial load
Bridge Resistance	700 to 1400 ohm, axis dependent
Compensated Temperature Range	-40 to 125 C (-40 to 257 F)
Excitation Voltage	10 VDC
Insulation Resistance from Bridge to Case	Exceeds 1000 Mohm
Vehicle Power Input Voltage	10 to 36 VDC

Mass of Components, Typical

Component	LW9.5	LW9.5T
	lbs (kg)	lbs (kg)
Wheel Load Transducer	6.5 (2.9)	4.4 (2.0)
Amplifier Package	1.3 (0.6)	1.3 (0.6)
Slip Ring and Encoder	0.5 (0.2)	0.5 (0.2)
Hub Adapter		
Wheel Adapter		
Fasteners (approximate)		
Load Wheel Interface Electronics	3.0 (1.4)	3.0 (1.4)

System Components

The Wheel Load Measurement System is made up of multiple components.

Transducer

Six Axes Wheel Force Transducer.

Load Wheel Interface

Load Wheel Interface Electronics. The dimensions are 8.5in x 1.6in x 8.6in (216mm x 42mm x 219mm). See page 20 for operating information.

Amplifier and Slip Ring

The amplifiers have been selected to have low thermal drift and excellent common mode rejection. They have a gain-bandwidth product of 2 MHz. The maximum gain used with the 6-axis Wheel Force transducer is 1000. The resultant 3-dB bandwidth at this gain is 2000 Hz. Channels with gains less than 1000 will have higher bandwidths.

The amplifiers have fixed gain and calibration resistors. These have been selected to match a specific transducer to provide uniform sensitivities among all channels. The resistors have precision accuracy and low temperature coefficients for better measurements.

A Twenty circuit Slip ring with 512-pulse encoder is mounted to the amplifier package.

Hub Adapter

The hub adapter mates to the smaller bolt circle of the transducer and is designed to match the offset of the production wheel. If used in conjunction with modified production rims, a new hub adapter is required for each wheel offset and bolt circles.

Wheel Adapter

Wheel adapters or modified wheel rims can either be machined out of a billet or made from a production rim. A stainless steel or aluminum ring the diameter of the wheel is welded into the production rim. It is then machined flat and concentric to provide the proper pilot diameter and bolt circle to match the transducer.

Alternately, adapters can be made to work with lightweight racing wheels, manufactured by BBS. These wheels are 2 piece rims that bolt together. The inner and outer rims are available in half-inch increments and a variety of diameters. By using these, most wheel offset and diameters can be matched without a new hub or wheel adapter. In addition, these wheels can save significant weight compared to modified production wheels.

Signal Cable

Signal Cable connects from the slip ring to the Load Wheel Interface Electronics (20ft/6m length).

Power and Signal Breakout Cables

Signal Breakout cable Left (5ft/1.5m length); Power Supply cable with fuse Right (8 ft/2.4m length).

Load Wheel Interface Remote

The Remote allows the user to control the Load Wheel Interface electronics from outside the vehicle. This makes Zero and Shunt operation more convenient, where the user does not have to go in and out of the vehicle to control the electronics. The Remote also displays all the same LED's that the Load Wheel Interface electronics do. This gives the user feedback and status of the electronics. If an error is detected on any of the Load Wheel Interface electronics, the Remote displays the error light.

Assembly Instructions

Before Assembly

- Be sure that all mating surfaces are free of dirt.
- Inspect mating surfaces for nicks and scratches.
- Place cardboard or wood down where the sensor is being assembled.
- Use care when assembling the sensor to avoid damage to any part of the system.
- Use care when installing the tire to insure that the adapter mating surfaces and sensor do not get damaged.

Assembly

- Place the hub adapter as shown.

- Set the transducer on the hub adapter as shown.

- Install thirty-two 1/4-20 x 3/4-inch bolts hand tight. Temporary thread locker (e.g. blue Loctite) is recommended on these bolts.

- Place the transducer and hub adapter assembly into the wheel adapter as shown below. It is suggested that the installer be careful while doing this so as not to damage the waterproof coating on the sensor.

- Be sure to line up the socket clearance notches on the hub adapter with those on the sensor

Note: The tire can be installed before or after the transducer assembly is bolted together. If installing after, care must be taken to not damage the sensor, connectors or adapters.

- Install twenty-four 1/4-20 x 3/4-inch socket head cap screws. Use temporary thread locker (e.g. blue Loctite). Do not install the 4 bolts nearest to the connectors at this time. They are used later to mount the amplifier housing to the sensor.

- Torque all of the 1/4-20 socket head cap screws to 60 lb-in using a crisscross pattern.

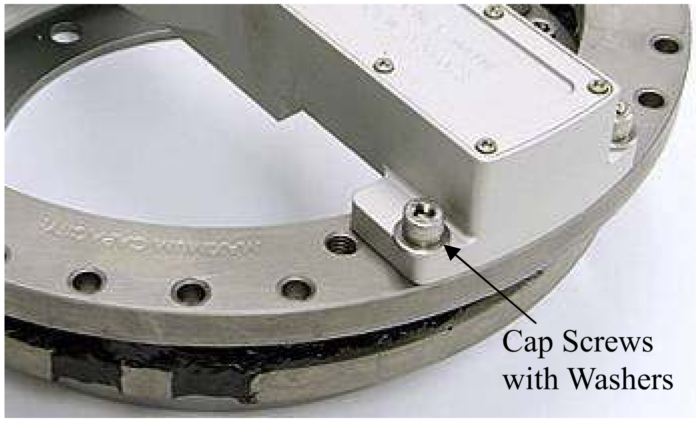
- Install the assembly on the vehicle. Tighten the lug nuts to the vehicle manufacturer's specified torque.

Amplifier Installation

Caution! *When using the wheel force transducers in a severe environment such as rocky terrain or near obstructions, it is suggested that stone shields be incorporated into the wheel adapters. Michigan Scientific can build them into the adapters if needed.*

- The amplifier and slip ring assembly is installed after the lug nuts have been tightened. Note that each amplifier and sensor is a matched pair. This is important; data is stored in the amplifier package for each specific sensor. Also note that there are dowel pins on the transducer to insure proper orientation of the amplifier housing.

- O-rings are used to provide weatherproof sealing between the amplifier housing and the sensor. Make sure the O-rings are in their proper place before installing the amplifier package.



- Secure the amplifier with four 1/4-20 inch stainless steel socket-head screws with washers and tighten to 60 lb-in torque. Temporary thread locker (e.g. Blue Loctite) is recommended on these fasteners.

- The slip ring is attached to the amplifier with 8-32 x 3/8-inch screws. Temporary thread locker (e.g. Blue Loctite) is recommended on these fasteners. The slip ring has been shipped already installed on the amplifier housing and is normally left attached to the amplifier housing when measurement system is removed from the vehicle.

Caution! *When removing the amplifiers, take care to pull off each side evenly. Failure to do this may cause damage to the dowel pins amplifier housing or connectors.*

- There is a red dot on the slip ring rotor and a similar dot on the stator. When the dots are lined up, the encoder is aligned with its once-per-rev index pulse. At this point the *X-axis* arrow on the amplifier housing points up. For this transducer, this is not zero angle. Zero angle occurs when the Z-axis is pointed down (see "Understanding SAE Coordinates" later in this manual for a discussion on Coordinates.)

- It is necessary to provide a rotational restraint of the slip ring stator. Normally the customer supplies the rotational restraint. For best results the rotational restraint should be attached to the steering knuckle or backing plate on the backside of the tire on a steered wheel. In this way the measured data is always with respect to the spindle coordinates even when the wheel is steered.

- A set of rotational restraints is included. Adjust the rotational restraints so that the top flat-surface of the slip ring is level. This is necessary to ensure that when the measurements are converted to vehicle coordinates the Z-axis represents a true vertical force on the vehicle. If the slip ring cannot be mounted vertically, see "Encoder Stator Offset Angle" on page 36.

- Connect one end of the cable to the slip ring. Fusion tape should be placed over the cable to slip ring connector to ensure a weatherproof connection. The tape also keeps grit from getting into the connector threads. The connector is difficult to remove if grit enters the threads.

- Secure the Load Wheel Interface electronics to the vehicle.

Caution! *It is important that the electronics be secured properly to the vehicle being tested. In addition to mounting to a rack in the vehicle, a tie-down strap should be passed over the top for additional security in case the latches are not secured properly or they fail.*

- Connect the other end of the cable to the Load Wheel Interface electronics.

Caution! Due to the severe environment expected with ATV's it is important that all cables be restrained properly. All cables must be secured to prevent movement of the connectors relative to the electronics.

- Connect the power cable to the Load Wheel Interface electronics.
- Connect the other end of the power cable to a DC voltage source in the range of 10 to 36 volts.
- Connect the cables between the data acquisition system and Load Wheel Interface electronics.
- Connect a cable from the banana jack in the back of one of the Load Wheel Interface Electronics to the vehicle chassis ground. If multiple units are being used, only one has to be connected to chassis ground.
- Turn the power switch on.
- At this time, the force, moment, and position channels are held at zero until the Load Wheel Interface receives an index pulse.

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Load Wheel Interface Electronics

Introduction

One Load Wheel Interface Electronics is used for each wheel force transducer. It handles coordinate transformation and the user interface. A zero procedure automates the sensor-offset adjustment. Options allow the sensor to be used in both rotating or non-rotation modes and control bridge excitation. The user selects which side of the vehicle the sensor is placed and corrections will be made to keep the output in SAE coordinates. Cross-axis sensitivity correction is performed. Error checking is in place to alert the user if the system is out of tolerance. Finally, a shunt procedure calculates output sensitivities and allows the user to record shunt values.

Caution! *While every effort has been made to make the electronics and enclosure as rugged as possible, the Load Wheel Interface units are not indestructible. The operator is encouraged to properly secure and protect them to prevent costly repairs.*

Caution! *The Load Wheel Interface Electronics is not weather or dust proof. When used on a vehicle that is not enclosed, protection must be provided to prevent damage.*

Lights and Controls

All controls located on top of the enclosure are momentary contact switches. They correspond to the labels located on the front panel. Power and position controls are located on the front panel.

Power Switch

Note: It is good practice to first connect all cables to the interface electronics before powering it up. If this is not done, possible damage may occur. In addition, the Interface reads important transducer information, from the amplifier package, at startup. Incorrect offsets and gain settings may be used if this information is not read.

The power switch turns the power on and off. When the Load Wheel Interface is turned on, it defaults to Run Mode with the Vehicle Coordinates and Bridge Excitation On. This will be indicated by green lights on the front panel. Sensor offsets, sensitivities, and other information is read from the smart sensor during power up.

Zero

The Zero light indicates that the module is performing a zeroing sequence, invoked by the Zero button on top of the enclosure. This button is only active during the Setup Mode. The light is also used to indicate an error in the zeroing sequence when used in conjunction with the Fault light. The zeroing sequence records data and calculates an offset value. This offset is recorded into the smart chip located in the amplifier package so it is not lost when power is interrupted or a different Interface electronics is used. The Load Wheel Interface uses 2 or 8 revolutions of the tire to calculate the offset. If the wheel is not turning when the *Zero* button is pressed, the calculation will be based off of the next 2 revolutions. If the Load Wheel Interface senses that the wheel is turning, it uses 8 revolutions to get a better on-road-averaged value.

Shunt

The Shunt light indicates that the module is performing a shunt sequence, which is invoked by the Shunt button on top of the enclosure. This button is only active during the Setup Mode. The light is also used to indicate an error in the shunt sequence when used in conjunction with the *Fault* light. The shunt sequence commands the amplifier package to invoke a shunt calibration resistor at each strain gage bridge in the transducer. The Load Wheel Interface reads the voltage change, due to the shunt, and adjusts the gain of each channel to match the sensitivity programmed into the Amplifier Package. This calculated gain is recorded into the smart chip also located in the amplifier package so it is not lost when power is interrupted or a different Interface is used.

Mode

The Mode lights indicate whether the module is in Setup or Run Mode. The *Mode* button on top of the enclosure toggles between the modes. Run mode is used whenever data is being collected. Setup mode is only used when the transducer is being set up or when the operator is checking the transducer offsets. Zero and Shunt sequences cannot be invoked unless the Interface has been switched to Setup mode.

Bridge Power

The *Bridge Power* light indicates whether excitation is being supplied to the strain gage bridges. When the light is illuminated, power is being supplied to the bridges. The Bridge Power button on top of the enclosure toggles the bridge power on and off. You may want to kill the bridge excitation to check for background noise. With bridge excitation interrupted, any signal activity is noise. It is best to perform this operation with the engine on and vehicle moving. The bridge power light goes off when the *Bridge Power* button on top of the enclosure is pressed. At this time, the module does not transform the data to *vehicle coordinates* and will perform no other function until the bridge power is turned back on.

Coordinates

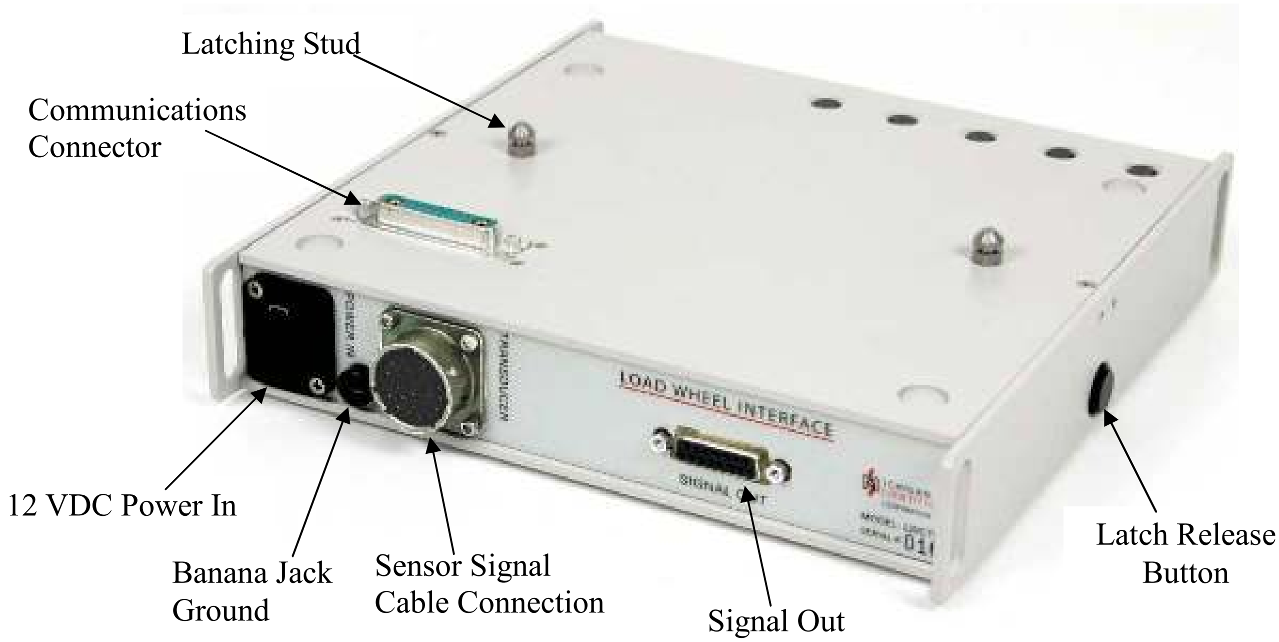
The *wheel* and *vehicle* lights indicate whether the output data is in *wheel* or *vehicle* (spindle) *coordinates*. The button on top of the enclosure toggles from one to the other. *Wheel* coordinates output the data directly from the wheel. This is used during laboratory testing when the transducer is not spinning. *Vehicle coordinates* transform the data from the *wheel coordinates* to *vehicle coordinates*. This is used for on-vehicle tests where the wheel is spinning.

Fault

The fault light indicates that there is a problem with the module. It can be lit in conjunction with other lights or by itself. More information is available in the trouble shooting section of this manual.

Position

The position knob is used to tell the module which side of the vehicle the sensor is on. The module uses different coordinate transformation equations for the right and left sides of the vehicle. There are 10 possible positions listed on the switch, 5 for right and 5 for the left. These are for keeping track of which Interface electronics is for which wheel when multiple enclosures are stacked up.



Connectors

Connectors located on the back panel of the Load Wheel Interface are for power, ground, sensor cable, and signal out. The connectors located on top and bottom of the enclosure are used to connect multiple Load Wheel Interface electronics together.

Output Channels

Eight analog outputs are available at the D-Sub connector shown in the photograph above. The first 6 channels are for force and moments about the x, y, and z axes. The last 2 are Wheel velocity and Wheel position.

Output Channel Sensitivities

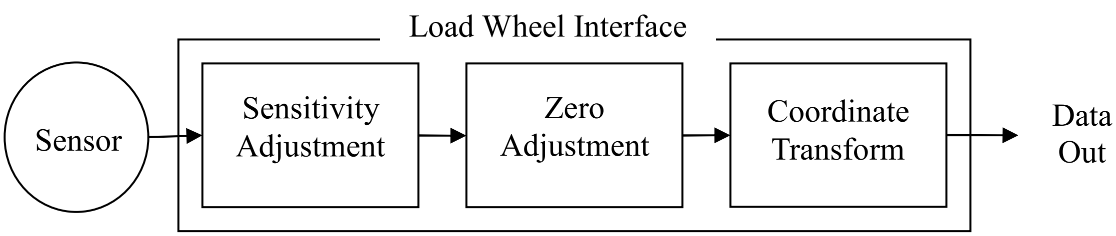
The output channels for all systems are scaled as shown below.

Output Channel Sensitivities		
X Force	1,000 lbs/V	4,448 N/V
Y Force	1,000 lbs/V	4,448 N/V
Z Force	1,000 lbs/V	4,448 N/V
X Moment	1,000 lb-ft/V	1,356 N-m/V
Y Moment	1,000 lb-ft/V	1,356 N-m/V
Z Moment	1,000 lb-ft/V	1,356 N-m/V
Velocity	180 RPM/V	
Position	36 deg/V	

Zero and Shunt Control Function Table				
Zero	***Shunt***	***Mode***	***Bridge Power***	***Coordinates***
N/A	N/A	Run	On	Wheel
N/A	N/A	Run	On	Vehicle
Stationary	Shunt	Setup	On	Wheel
Rolling	Shunt	Setup	On	Vehicle
N/A	N/A	N/A	Off	N/A

The above table shows different possible zero procedures that result with different Mode and Coordinates settings.

Load Wheel Interface Data Flow



Data is processed inside the Load Wheel Interface electronics. The above graphic shows the flow of data into and out of the electronics.

Output Channel; Offset, Sensitivity and Transform Function Table					
Control States			Outputs		
Mode	Coordinates	Bridge Power	Offset Adjustment	Sensitivity Adjustment	Coordinate Transform
Run	Wheel	On	Yes	Yes	No
Run	Vehicle	On	Yes	Yes	Yes
Setup	Wheel	On	No	Yes	No
Setup	Vehicle	On	No	Yes	No
N/A	N/A	Off	No	Yes	No

Sensitivity adjustments are always performed to the data inside the Coordinate Transformation electronics. Offset adjustment and coordinate transformation are not always performed. The above table summarizes these states.

Multiple Load Wheel Interfaces

Each Load Wheel Interface is used with one Wheel Force Transducer. When using multiple Wheel Load Measurement systems, the Load Wheel Interface is designed to be stacked. Latch studs are mounted on top of the enclosure and a latching mechanism is mounted on the bottom. When the boxes are set on top of each other, they latch together. A button on each side of enclosure releases the latches. Electrical connections are made via the D-sub connectors mounted on top and bottom of the enclosure. When not stacked it is recommended that the dust covers provided with the enclosure be used to cover the D-sub connectors. This will protect the connectors and reduce the chance of electrical damage to the electronics.

The Load Wheel Interface electronics communicate with each other using a CAN bus interface. This allows the operator to control all of the interfaces with one set of controls. Notice that the control buttons are located on top of the enclosure. When one interface is stacked on top of another, the buttons on the lower one are covered. All functions are controlled by the top interface at this time.

A base is available to provide better stability and tie down locations. This base also protects the D-sub connector on the bottom interface.

The power supply cable can be connected to any one of the Load Wheel Interface electronics. That interface will supply power to the rest in the stack.

Each Load Wheel Interface retains its own power switch and must be turned on individually. At power up, the Interface checks the state of the other boxes and then sets itself to match.

Up to six Load Wheel Interface electronics can be stacked together. If you want to stack more together, please contact Michigan Scientific to discuss your specific application.

Power Requirements

The Load Wheel Interface requires 10 to 36 VDC power. Power draw is less than 1.0 amp at 12 volts for each Load Wheel Interface.

A power cable is provided with each Load Wheel Interface. This cable is fused at the end closest to the vehicle power supply. If a replacement cable is made, be sure to include a fuse.

Balancing - Zeroing

An electrical balance is critical to assure accuracy of wheel load measurements. Any electrical zero offset in the transducer or amplifier can introduce significant errors in the measurements. When measurements that are made on the rotating transducer are transformed to the stationary *vehicle coordinate* system, any zero offsets produce errors that are periodic at once-per-revolution. It is therefore important to reduce all zero offsets to a minimum.

The wheel load transducer is electrically balanced during fabrication. It is then temperature compensated to have minimum balance shift from –40 up to 200°F. The amplifiers and Load Wheel Interface are also designed to have minimal thermal offset over a wide temperature range.

The Load Wheel Interface has a Zero feature that automates the zeroing process. With any zeroing method used below, it is recommended that the sensors be exercised before any zeroing is done. To exercise the transducers, simply drive the vehicle around a parking lot.

There are three zeroing procedures.

1. Zeroing on the Hoist

This Zeroing method uses the weight of the wheel and tire to determine the zero offsets. This method is recommended for best accuracy.

Caution! While it does not matter which direction you turn the wheel during the zero sequence, it will cause an error if the direction of rotation is reversed during the zeroing sequence. Remember when turning one wheel on a drive axle, the one on the other side will turn the opposite direction. This is OK as long as the wheel does not change direction of rotation during the sequence.

- Turn on the Load Wheel Interface.
- Lift the tires clear of the ground.
- Press the *Setup Mode* button.
  - The blue *Setup Mode* light will illuminate.
- Press the *Zero* button. Note: The wheel must not be rotating when the *Zero* button is pressed.
  - The amber *Zero* light will illuminate.

Caution! While it is not important that the wheel be turned at a steady rate, do not impart excessive acceleration or deceleration to the wheel while turning it. This may cause calculation errors. To reduce errors, the Load Wheel Interface uses position-based sampling for this procedure.

- Rotate the sensor. When rotating the sensor, never apply force to the tire itself. This can cause an error in the zero calculations. If possible, rotate the assembly using the vehicle axle. If there is no access to the axle, forces can be applied to the amplifier package. Notice that these forces will go through the sensor and possibly cause errors. Rotate in one direction until the amber *Zero* light goes out, this should take 2 revolutions.

Using more than one sensor with stacked interface boxes

- You may rotate each sensor independently.
- To zero only one wheel, you will need to turn off the interface electronics, on the wheels that you do not want to zero, or un-stack them.

When the Load Wheel Interface box completes the zero procedure, it will write the calculated offset value to the smart chip located in the amplifier. This way the sensor does not need to be zeroed every time the power is interrupted or if a different interface box is used with the sensor.

2. Rolling Zero on the Road

This Zero method uses the weight of the vehicle to determine the zero offsets. The Fy (Lateral) transducer channel may have real, non-zero values during this mode of operation due to toe-in and tire conicity The My (Torque) may also have a real non-zero value due to drive line torque and brake or seal drag. Use rolling zero only when lower accuracy can be tolerated.

- Press the *Setup Mode* button.
- The blue *Setup Mode* light will illuminate.
- Coast the vehicle along a smooth and level section of road or parking lot.
- Press the *Zero* button.
- The amber *Zero* light will illuminate.
- The Load Wheel Interface detects that the tires are turning and will use the average of the next 8 revolutions to compute the offset.
- Once the procedure is complete, the light will go out.
- When the Load Wheel Interface box completes the zero procedure, it will record the calculated offset value to the smart chip located in the amplifier. This way the sensor does not need to be zeroed every time the power is interrupted or if a different interface box is used with the sensor.

3. Stationary Zero

This Zero method is only used in non-rotating applications, such as a simulator. It allows the user to null the output from the transducer.

- The Load Wheel Interface electronics defaults to *Vehicle Coordinates* at startup.
- Press the *Coordinates* button.
- The blue *Wheel* light will illuminate.
- Press the *Setup Mode* button.
- The blue *Setup Mode* light will illuminate.
- Press the *Zero* button.
- The amber *Zero* light will illuminate.
- Once the procedure is complete, the light will go out.
- When the Load Wheel Interface box completes the zero procedure, it will write the calculated offset value to the smart chip located in the amplifier. This way the sensor does not need to be zeroed every time the power is interrupted or if a different interface box is used with the sensor.

Once the initial setup is accomplished, data collection can continue for several days without readjustment. The vehicle should be lifted occasionally to verify the zero stability.

Verifying the Zero Procedure

To check the quality of the zero, set the Load Wheel Interface to *Run* mode and *Vehicle* coordinates. Observe the output from each channel with the wheel lifted off of the ground. The x and y-axes forces should have very little output. The z-axis force should read the negative weight of the wheel and tire. The y and z-axes moments should have little output. The x-axis moment should have some output proportional to the weight of the wheel and tire multiplied by the moment arm from the wheel centerline to the sensor centerline.

Spin the wheel and observe the x and z-axes force outputs. There should be very little ripple in the outputs. Offset errors will cause once-per-rev variations. Scaling errors will cause twice-per-rev errors. If excessive once-per-rev errors are seen, repeat the zero process. If excessive twice-per-rev errors are seen, perform a shunt sequence and repeat the zero procedure.

For this sensor, the allowable output variations are plus and minus 0.25% of rated load or 20 lbs. for x and z-axes force channels.

Factory Calibration

Calibration values and cross-axis sensitivity coefficients are programmed into the amplifier for each sensor. The wheel load sensor was statically calibrated in a load frame with a rigid outer ring in place of the modified rim.

An electrical shunt calibration was performed during physical calibration in the laboratory. During physical calibration, shunt resistor values are determined to establish equivalent physical load values. Shunt calibration resistors in the amplifiers were chosen to provide an electrical signal equal to approximately 25-50% of the rated capacity. Sensitivity calibration values in kilo-Newton/volt and pounds/volt are presented in the Appendix of this manual.

Radial forces were applied around the perimeter of the outer ring at 45^{o} intervals. The forces were applied in each direction and data was recorded. The data were then fitted with least squares linear functions. Cross-axis sensitivity in each of the non-loaded axes were also recorded and fit with a linear approximation.

The calibration procedure was repeated with pure torque applied around each moment axis.

Shunt Calibration Sequence

The amplifiers have a remote calibration feature that applies the shunt resistance at the transducer. When the transducer is installed on a vehicle the shunt calibration feature is used to set the sensitivities in the Load Wheel Interface.

Note: This sequence can be performed with the wheels on or off the ground with equal accuracy. However, if the wheels are on the ground, anything that causes force variations such as movement in the vehicle can cause errors in the shunt cal.

To invoke the shunt cal, the Load Wheel Interface must be in *Setup Mode*.

- Start up the Load Wheel Interface.
- Press the *Mode* button on top.
  - The blue *Setup* light will illuminate.
- If the vehicle is sitting on the ground, be sure that there is no movement in the vehicle during this sequence.
- Press the *Shunt* button on top.
  - The amber *Shunt* light will illuminate.

The output from the interface will.

- Go high for 4 seconds,
- Return to zero for 4 seconds,
- Go low for 4 seconds,
- Return to zero once the sequence is complete.

The interface uses the shunt to calculate a scale factor for the output, force and moment-channels. This scale factor is recorded into the smart chip located in the amplifier electronics. This insures that the sensitivity does not need to be recalculated every time power is interrupted or if a different load wheel interface is used.

If the new sensitivity differs from the factory sensitivity by more than two percent, the fault light will illuminate and the *Shunt* light will stay lit. See the trouble-shooting section of this manual for more information.

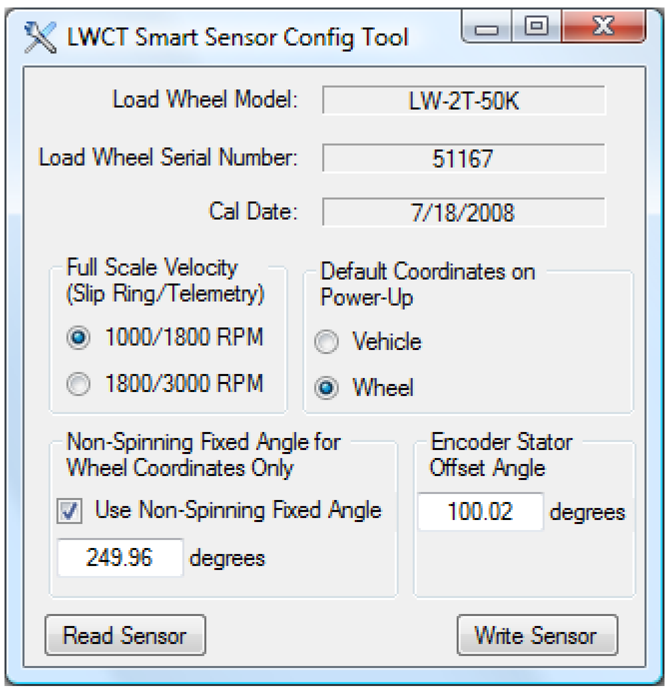
The calibration sheet lists sensitivity in lbs./Volt and N/Volt and a shunt values in pounds and Newton's for each channel. If desired, the user may check the sensitivity by recording the outputs during a shunt sequence and calculating the delta (magnitude of change from positive shunt to negative shunt). The shunt value listed in the calibration sheet is defined as half of this delta.

In-field checkout can be done by parking the vehicle on a scale and comparing the transducer outputs with scale values. The scale values will differ from the output of the sensor by a little more than the weight of the tire and rim adapter. Physical re-calibration services are available from Michigan Scientific. Re-calibration is unnecessary if the zero balance remains consistent and the shunt calibration produces the voltages given on the calibration sheets.

Software Selectable Options

LWCT Smart Sensor Config Tool software can be used to set various options for each wheel force transducer. The settings are stored in the Smart Chip, located in the Amplifier package. At startup, the LWCT reads this information and sets up accordingly. These options include Full Scale Velocity, Default Coordinates on Power-Up, Non-Spinning Fixed Angle and Encoder Stator Offset Angle. To use *LWCT Smart Sensor Config Tool*, install the software as directed in Appendix 2. This software requires Windows XP or newer.

To read the data from the sensor, connect one end of the cable provided to the signal cable and the other end to the computer's USB port. Connect the other end of the signal cable to the slip ring stator connector. Start the LWCT Smart Sensor Config Tool and press the *Read Sensor* button. Make necessary changes, as described below. Press the *Write Sensor* button to transmit the data to the smart chip.



Full Scale Velocity

This setting is used to set the full scale velocity of the wheel speed signal derived from the encoder. There are two optional full scale velocities. When used with slip rings (like this system), the full scale velocities are 1,000 rpm at 10V and 1,800 rpm at 10V (1,800 and 3000 are for telemetry systems). The default setting of 1800 rpm per 10 volts is listed in the Output Channel Sensitivities table on page 24.

Default Coordinates on Power-Up

The LWCT is set up, at the factory, to default to *Vehicle* coordinates at start up. For most on-the-road testing, this is desired. However, when used on a simulator, the LWCT should be in Wheel coordinates. (For an explanation of *Wheel* and *Vehicle* coordinates, see page 23.) The operator must remember to change the coordinates setting to *Wheel coordinates* each time power is cycled. This option allows the user to change the default to *Wheel coordinates* at startup so that it is not necessary to make this change each time the LWCT is powered up

Non-Spinning Fixed Angle

This option is used on a simulator when the transducer cannot be mounted vertically (i.e. +Z is not pointing straight down). If the transducer is not vertical, the forces and moments will not be applied in the correct orientation with respect to the vehicle. If the transducer cannot be mounted vertical, measure the angle that the transducer is rotated from vertical in the *clockwise* direction. Enter that number into the appropriate box in the Smart Sensor Config Tool. The LWCT uses this information to correct the orientation of the forces and moments. The LWCT only uses this information when in *Wheel coordinates*.

Encoder Stator Offset Angle

In some situations, the slip ring body cannot be oriented with the sides vertical. The slip ring is the angle reference for the LWCT to transform the data from wheel to vehicle coordinates. If the slip ring cannot be mounted vertically, measure the angle that the slip ring body is from vertical in the clockwise direction. Enter that number into the appropriate box in the Smart Sensor Config Tool. The LWCT uses this information to correct the reference angle when performing coordinate transformation.

Caution! *When using a stator restraint rod that connects to the vehicle fender (or some other part that does not move with the wheel) be sure that the slip ring body stays vertical during the entire suspension travel. If a stator restraint rod is connected to the fender, it must be vertical to prevent any angle change.*

Sensor Offset Check

It is recommended that the customer keep track of the transducer offset over time. If the offsets for each channel remain consistent with the factory offset listed on the calibration sheet, re-calibration is not necessary.

- Remove hub and wheel adapters. Hub and Wheel adapters can cause a small shift in transducer offset when they are bolted up. This is normal and the sensor will return to its original offset once they are removed.
- Set the sensor flat on the bench.
- Connect the amplifier to the sensor.
- Connect the cable to the slip ring and Load Wheel Interface.
- Power up the interface.
- Press the *Mode* button to put the interface into *Setup mode*.
- Record the output for each channel.

Cross-Talk

The cross-axis sensitivity was measured in a rigid laboratory test fixture with matched amplifiers. These numbers are recorded in the smart sensor where the Load Wheel Interface uses them to correct any errors due to linear cross-axis sensitivity.

Insulation Check

Insulation resistance of the wheel load transducer bridge circuits to the metal should be checked occasionally or if malfunction is suspected. The insulation resistance should be greater than 1000 M-ohms. Lower insulation resistance values may result from contamination of the connectors or breakdown of the strain gage insulation. If care is taken to clean the connector area and low values persist the transducer should be returned to Michigan Scientific for correction and re-calibration. The pin-out is listed below.

Wheel Force Transducer-to-Amplifier Connector Pin-Out	
13 pin military	
Pin Numbers	Function
1	X Power +
2	X Signal +
3	X Signal -
4	X Power -
5	Y Power +
6	Y Signal +
7	Y Signal -
8	Y Power -
9	Z Power +
10	Z Signal +
11	Z Signal -
12	Z Power -
13	Shield

There are two transducer-to-amplifier connectors. One is used for the force channels and the other for moments. These are labeled on the front of the amplifier package.

Weatherproofing

All connectors should be covered with fusion tape to keep water and dust out of the connectors. The connectors are designed to be weatherproof but the tape provides some extra protection.

Coordinate Transformation to Wheel Mid-plane

The Load Wheel Interface electronics resolve the forces and moments to the intersection of the axis of rotation and a plane through the middle of the sensor ring. The forces and moments can be resolved to the intersection of the axis of rotation and the mid-plane of the wheel, in the data acquisition system or by post processing. The forces and Y Moment do not change. The X and Z Moments change in relation to the radial force and the distance from the wheel mid-plane to the transducer mid-plane. The equations are listed below.

Right side of the vehicle:

Mxmp = Mxv + Fzv * R

Mzmp = Mzv + Fx * R

Left side of the vehicle:

Mxmp = Mxv - Fzv * R

Mzmp = Mzv - Fx * R

Where:
Mxmp = X Moment at the tire mid plane

Mzmp = Z Moment at the tire mid plane

R = the distance from the sensor centerline to the wheel centerline. This distance must be expressed in either feet or meters to keep the units consistent.

Wheel Offset Considerations

Wheel offset from the centerline of the tire to the centerline of the transducer produces a moment about the vehicle X-axis due to the vertical load. When considering the load rating of the transducer, this moment is added to the moment produced by side loading at the tire patch.

Rotational Restraints

The preferred method of providing a rotational restraint of the slip ring on a front wheel is by means of a strap that goes up and over the tire to the knuckle or backing plate. A simple rod from the slip ring to a loop on the body is usually sufficient for a rear wheel. Simple rotational restraints with magnetic body brackets are available from Michigan Scientific.

Sampling Frequency

Much of the work done with load wheels is for wheel or chassis load measurement with a frequency of interest below 100 Hz. A sampling rate of 1,000 samples/second and pre-sample filter of 400 Hz. are usually adequate. This gives a sample approximately every 6 inches (15 centimeters) of a wheel traveling at 150 mi/hr. For impulsive loads such as that encountered when striking a pothole, a sampling rate of up to 4000 samples/second may be necessary to define the peak loads to within a few percent.

Understanding SAE Coordinates

SAE Coordinates define positive X-axis as directed towards the front of the vehicle, positive Y-axis to the driver's right and positive Z-axis into the ground. Associated moments are per the *right hand rule*. See figure below.

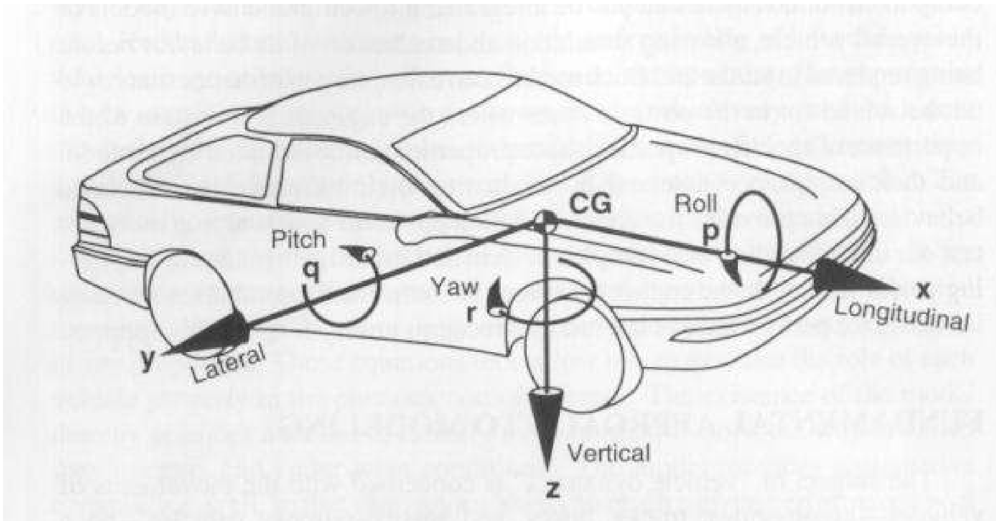


Fig. 1.4 SAE Vehicle Axis System.

Positive transducer output is defined as a force or moment applied by the spindle to the tire per positive SAE coordinate directions e.g. +Fz WFT data is the spindle forcing the tire down (i.e. tire forcing spindle up). It is good measurement engineering practice to perform a system polarity check on each channel by physically loading (e.g. manually pushing/pulling/twisting) the transducer. With regards to the WFT/LWCT-TEL measurement system, the origin of the SAE coordinate system is placed at the perpendicular intersection of the axis of wheel rotation and an imaginary plane that passes through the centerline of the transducer's spokes.

The WFT channels are defined as:

Fx = Longitudinal Force
Fy = Lateral Force
Fz = Vertical Force
Mx = Roll Moment (Wheel Camber)
My = Pitch Moment (Wheel Torque)
Mz = Yaw Moment (Wheel Steer)

Troubleshooting

Symptom	Possible Causes	Solution
Load Wheel Interface Does not power up when the power switch is turned on.	Fuse on power cord is blown.	Replace Fuse with 15-ampere automotive fuse and try to power up the interface again.
	Power cord not connected to power.	Check that power cord has power supplied to it and try to power up the interface again.
	Power supply polarity is incorrect.	Check polarity, if incorrect, reverse power supply leads and try to power up the interface again.
Fault light illuminates at startup	Signal cable not connected properly.	Check signal cable connections. Cycle power, leave box off for 5 seconds before turning back on
	Smart chip communication failure.	Cycle power, leave box off for 5 seconds before turning back on
Fault light illuminates immediately after a button is pressed.	Internal communication error	Cycle power, leave box off for 5 seconds before turning power back on, Resume operation
After zero sequence, Zero light does not go out and fault light illuminates.	Failure to record data to smart chip	Check cable connections, cycle power, and repeat the zero sequence.
After zero sequence, Zero light goes out but Fault light illuminates.	Sensor offset greater than 4 volts. The electronics will still zero the channel that has greater than 4 V offset but it alerts the user. This condition can cause the system output to saturate before it reaches full scale. The Fault light will go out next time the power is cycled.	With wheel off of the ground, change Load Wheel Interface to *Setup* mode and check output voltages. Confirm which channel has an offset greater than 4 V. Unbolt the wheel adapter. If offset goes away, check adapter to see that it is not damaged. If offset does not go away, unbolt the hub adapter. If offset goes away, check adapter to see that it is not damaged. If offset does not go away, send sensor in to Michigan Scientific for Checkout and repair.

Symptom	Possible Causes	Solution
Shunt light does not go out and fault light illuminates after a shunt sequence.	Force input to the sensor during shunt sequence causes out of tolerance shunt.	Jack up vehicle, cycle power, and repeat the shunt sequence.
	Load Wheel Interface failed to record data in smart chip.	Check the cable connections, cycle power, and repeat the shunt sequence.
	Sensor is out of tolerance.	Send the sensor in for checkout and calibration.
Data has once-per-revolution wave form.	The zero is not correct.	Perform zero procedure.
	The tire can have stiffness variations, which will appear as once-per-revolution variations. This is a real force.	If force variation is not acceptable, replace the tire.
	Wheel adapter can be bent or out of tolerance. The force is real.	If force variations are not acceptable, replace the wheel adapter.
Data has twice-per-revolution waveform.	The sensitivities are out of tolerance due to incorrect or corrupted sensitivity values.	Perform the shunt sequence. It is important that no dynamic forces are imposed on the sensor at this time. These forces can come from movement in the vehicle. For best accuracy, lift the wheel off the ground.
	One of the strain gage bridges has failed.	Check the outputs during the shunt sequence and check the zero data when the interface is in setup mode. If the shunt value is not correct or the zero has shifted, send sensor in for checkout and repair.
Fx, Fy, Mx, and My channels look like a sin waves when wheel is turning	Interface is set to wheel coordinates.	Check status of lights on front panel. If the *Wheel Coordinates* light is illuminated, press the *Coordinates* button on top to change back to vehicle coordinates. Check outputs.
	Interface is in setup mode.	If the *Setup Mode* Light is illuminated, press the *Mode* button on top to change back to run mode.

Symptom	Possible Causes	Solution
Channels, which should have no load, have an offset even after the zero procedure is performed.	Data channels have error due to rolling zero procedure.	If the rolling zero procedure was performed on the road, there will be real forces that will be zeroed out. For best accuracy, perform the zero on the hoist. Further discussion is in the zeroing section of this manual
	Slip Ring is not oriented properly.	See "Angle reference incorrect" below
	Incorrect zero, direction of wheel rotation was changed during the zero procedure.	Be sure that the wheel is turned only in one direction during the zero procedure.
	External forces were imposed during the zero procedure on the hoist.	When turning the wheels, be sure to apply force only on the amplifier package. This insures that no forces are imposed through the sensor.
	Incorrect zero, on-the-road zero was performed on a rough surface.	Redo the zero procedure. For best accuracy, perform the zero on the hoist.
	Data acquisition system has some offset.	Using a volt meter, check the outputs from the load wheel interface. If the outputs are indeed zero, null the offsets in the data acquisition system.
	Load Wheel Interface electronics are damaged.	Swap the Load Wheel Interface with another unit, if available, and try to zero it. If the problem goes away, send the interface electronics in for checkout and repair
	Offsets are too large for the load wheel interface to zero them. Damage to sensor.	The wheel may have been damaged. Remove from the wheel and hub adapters and place on the bench. Change the Interface to setup mode. Check the offset. If it is out of range, send in for checkout and repair.

Symptom	Possible Causes	Solution
Outputs from interface box stay zero for all channels even when force is present.	Load Wheel Interface is not turned on.	Check to see if the Load Wheel Interface is turned on.
	Encoder has not found an index pulse.	The output channels stay at zero until the encoder sees an index pulse. Turn tire at least one complete revolution. Check outputs.
	The bridge power kill feature is invoked.	Check to see if the bridge power light is on. If it is not, press the *Bridge Power* button. The light should illuminate.
	Signal cable from sensor has been disconnected.	Turn off the interface electronics, reconnect the cable and turn the interface electronics back on.
	Signal Cable from sensor has been damaged.	Inspect cable for damage. A cable diagram is located in the appendix.
	Output cable from the Load Wheel Interface is disconnected or damaged.	Check connection and inspect cable for damage
	The data acquisition cabling is not connected improperly.	Check the output from the interface with a volt meter. If the output is correct, check the cabling or data acquisition setup.
The channel offsets change during use.	A severe event caused some shifting in the bolted joints between the sensor and adapters.	While it is not common, a severe event could cause some offset in channels. Perform the zero sequence.
	A severe event overloaded the sensor.	Check the sensor offsets. Remove the wheel and hub adapters. Change the Load Wheel Interface to *Setup Mode* Check the offsets for each channel with a voltmeter. If the offsets have changed, send the sensor in for checkout and possible repair.

Symptom	Possible Causes	Solution
Higher or lower than expected output from one or more channels	The data acquisition system sensitivities are incorrect.	Check data acquisition system. The correct sensitivities are listed on the calibration sheet in the back of this manual.
	Incorrect amplifier package	Check that the correct amplifier package is being used with the sensor.
	Sensor is damaged.	Check the sensor offsets and shunt values. Send in for checkout and repair if needed.
	Amplifier package is damaged.	Send in for checkout and repair if needed
One or more output channels output incorrect polarity.	Right/Left Switch is not in the correct position.	Check to see if switch is correct. Change if needed.
	Cable to data acquisition is improperly connected.	Check the voltage from the Load Wheel Interface. If correct, check pin-out for signal cable to the data acquisition system.
	Sensitivity is incorrect in the data acquisition system.	Check the voltage from the Load Wheel Interface. If correct, check the sensitivities in the data acquisition system.
	Slip Ring is not oriented properly	See "Angle reference incorrect" below
Angle reference incorrect	Slip Ring is not oriented properly	Orient the slip ring so that the connector is pointed vertical. The side surfaces of the slip ring should be vertical.
	Encoder Stator Offset Angle entered incorrectly	Using the LWCT Smart Sensor Config Tool, first confirm that the angle stored in the smart chip is incorrect and then update with the appropriate angle.

Appendix 1

Wiring and Shielding

Wheel Load Measurement System Cable

SR20AW/E512 STATOR CONNECTOR
LS UNIT
Cable Revision F (2ND Version)

Revised
June 28, 2008

Slip Ring Mating Connector (Deutsch 26WE26SN) PINOUT	Cable WIRE COLOR	**LWCT Box** PT06E-16-26P(SR) PINOUT	FUNCTION
A	BLUE	A	+ 15 Volts DC
B	blue JUMPER	B	+15 Volts DC
C	GRAY	C	15 VDC Common
D	gray JUMPER	D	15 VDC Common
E	VIOLET	E	-15 Volts DC
F	violet JUMPER	F	-15 Volts DC
G	ORANGE	G	Calibration Control
H	BLACK (Smaller wire)	H	Smart Sensor
J	ORANGE	J	Fx High
K	WHITE (one of six)	K	Fx Common
L	GREEN	L	Fy High
M	WHITE (two of six)	M	Fy Common
N	BROWN	N	Fz High
P	WHITE (three of six)	P	Fz Common
R	GRAY	R	Mx High
S	WHITE (four of six)	S	Mx Common
T	RED	T	My High
U	WHITE (five of six)	U	My Common
V	VIOLET	V	Mz High
U	WHITE (six of six)	W	Mz Common
X	YELLOW	X	+5 to +20VDC
Y	WHITE	Y	Ground
Z	RED	Z	Output A
a	BROWN	a	Output B
b	WHITE	b	Output I
W	Drain Wire from Shield	c	Overall Shield

Note: On slip ring mating connector jumpers must be used. (Such as for pin A & B Blue and Blue Jumper) Jumpers Req.on LWCT Box Side.
So on LWCT mating Connector, we will place jumpers as well on A,C,and E….

Load Wheel Interface "Signal Out" Connector Pin-Out

15 Pin D-Sub Connector	
Pin Numbers	Function
1	Position High
2	Speed High
3	Mz High
4	My High
5	Mx High
6	Fz High
7	Fy High
8	Fx High
9	Position & Velocity Common
10	Mz Common
11	My Common
12	Mx Common
13	Fz Common
14	Fy Common
15	Fx Common

Load Wheel Interface "Power" Connector Pin-Out

Mating Connector for Power: Speak-ON part number: NLT4FX	
1+	Not Used
1-	Not Used
2+	Power High
2-	Power Ground

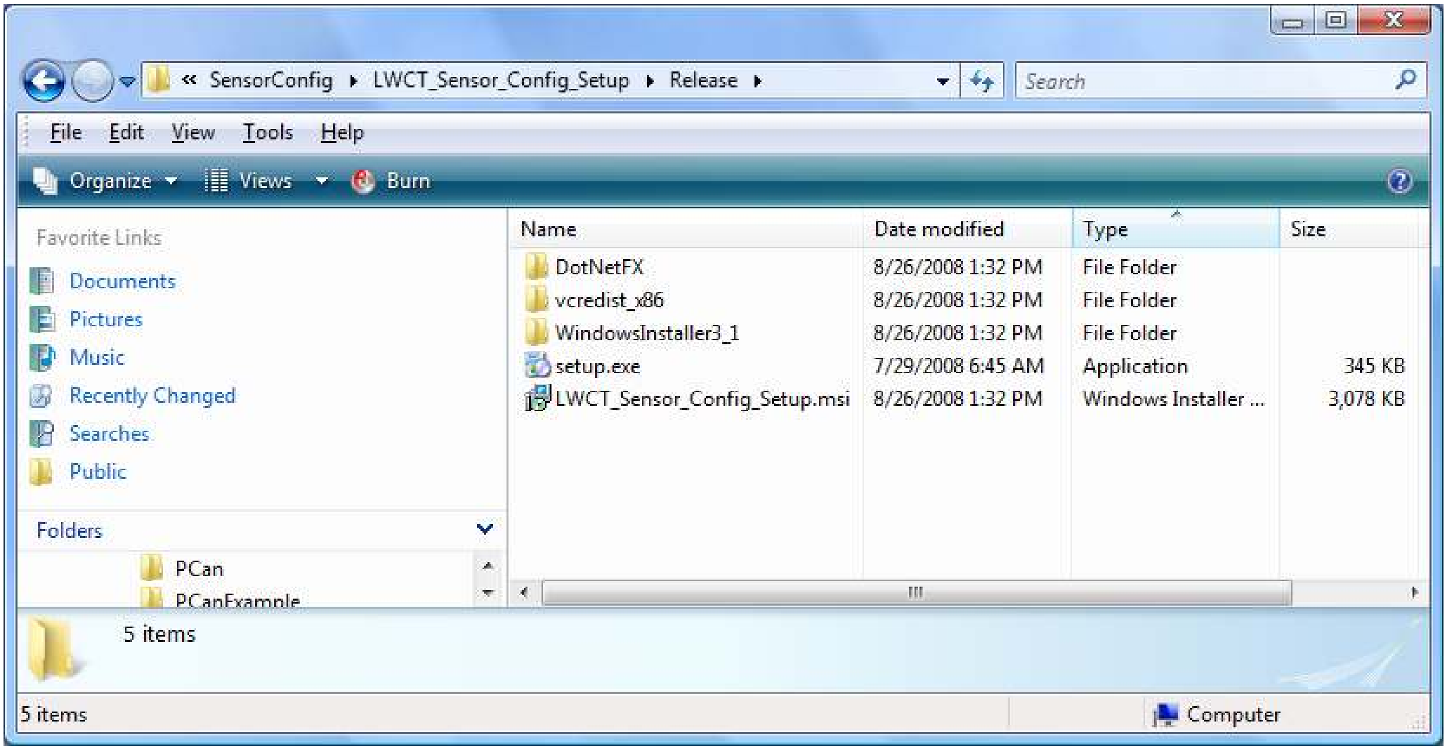
A 15-ampere fuse is located in the power cable. Be sure to include the fuse if building a new cable.

Appendix 2

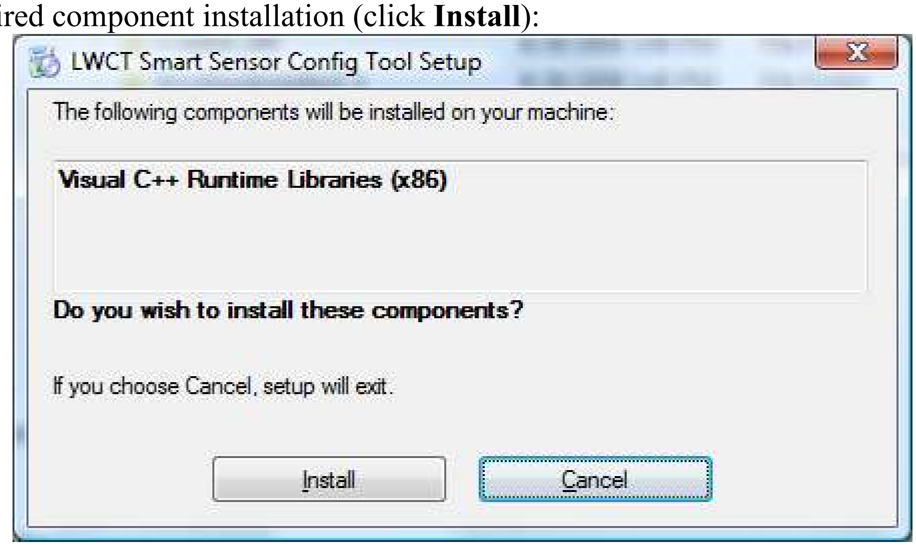
Software Installation

Sensor Config Tool Installation

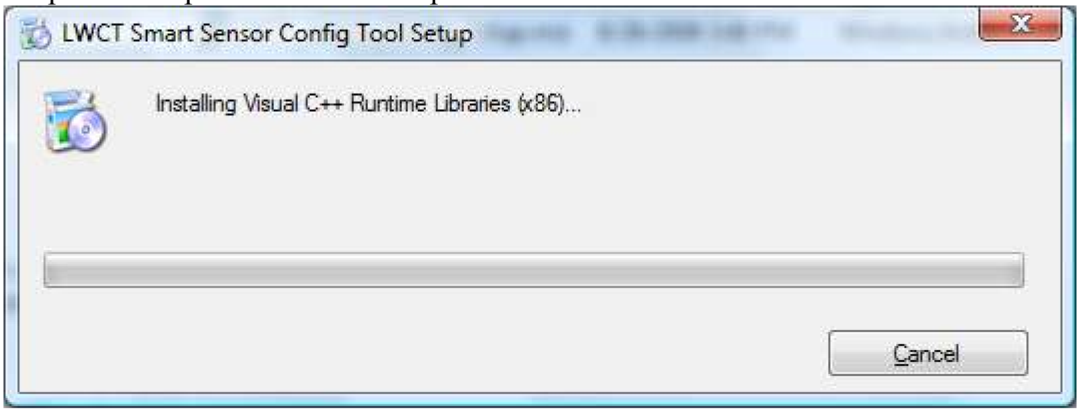
Double-click **setup.exe** in the setup folder:



The following 3 requirements will be installed if your computer does not already have them installed. Please allow them to be installed in order to complete the setup: Windows Installer 3.1, .NET Framework 2.0, Visual C++ Runtime Libraries (x86).
Example of required component installation (click **Install**):

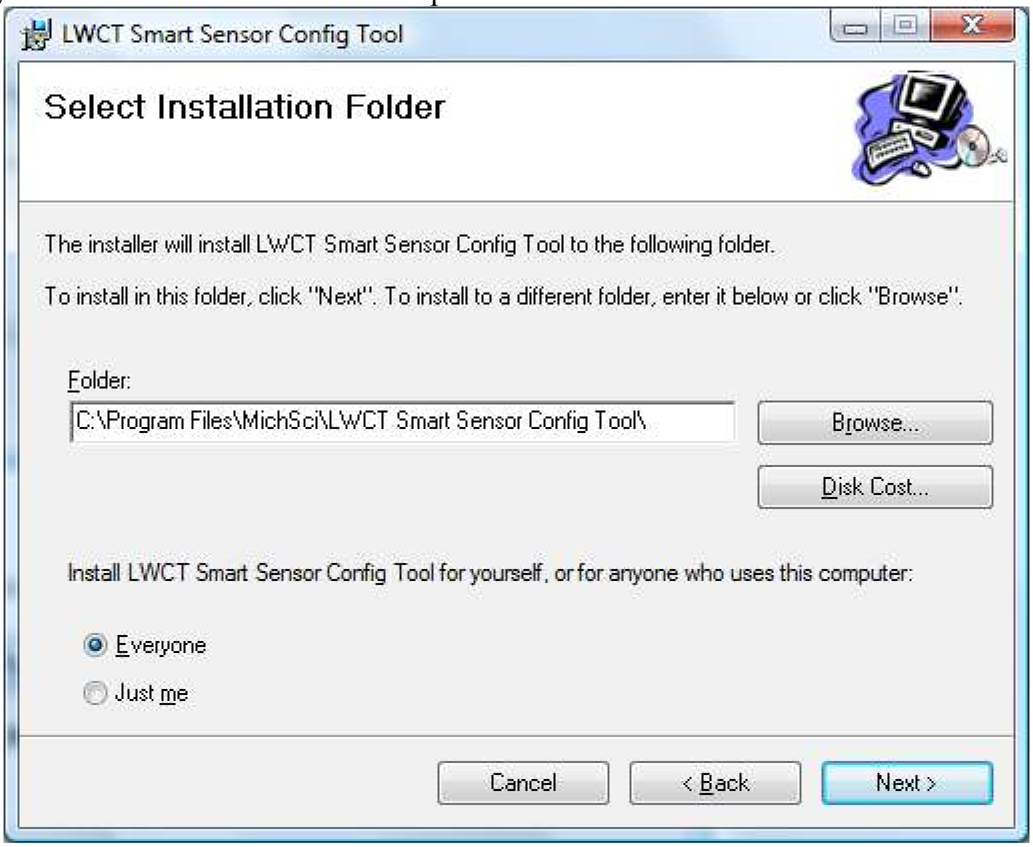


Example of required component installation process:

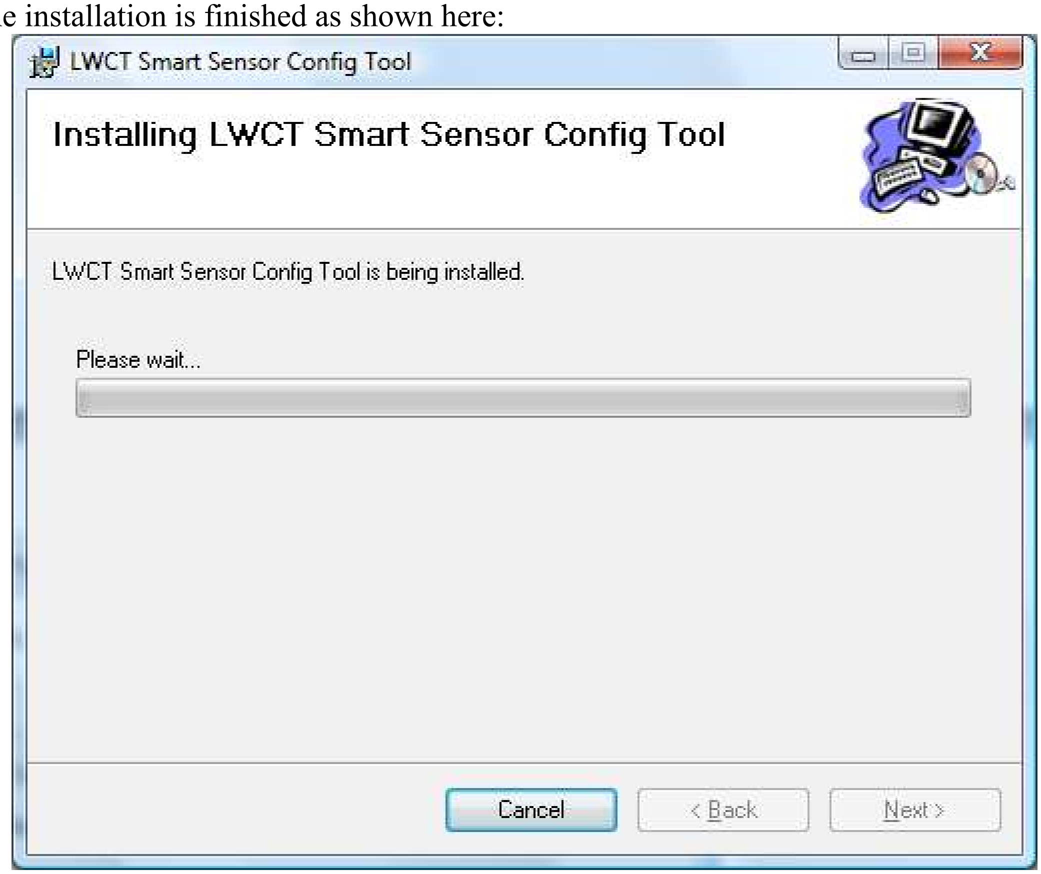


Click **Next** at the following screen to continue installation:

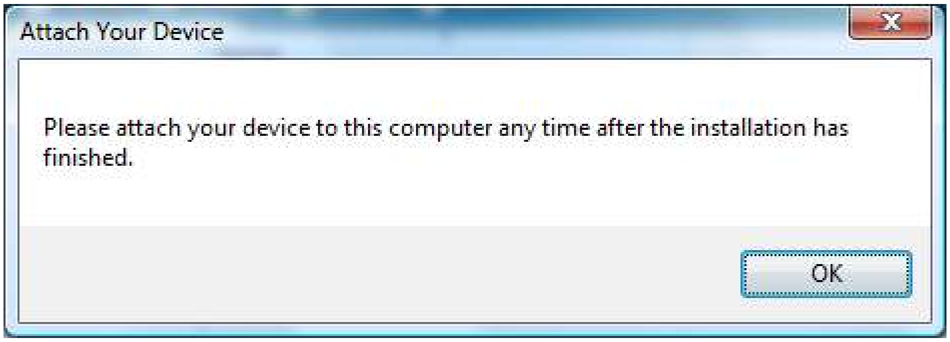
At this dialog you can either use the default installation folder or select a different one. Click **Next** when you are ready to continue with the installation process:



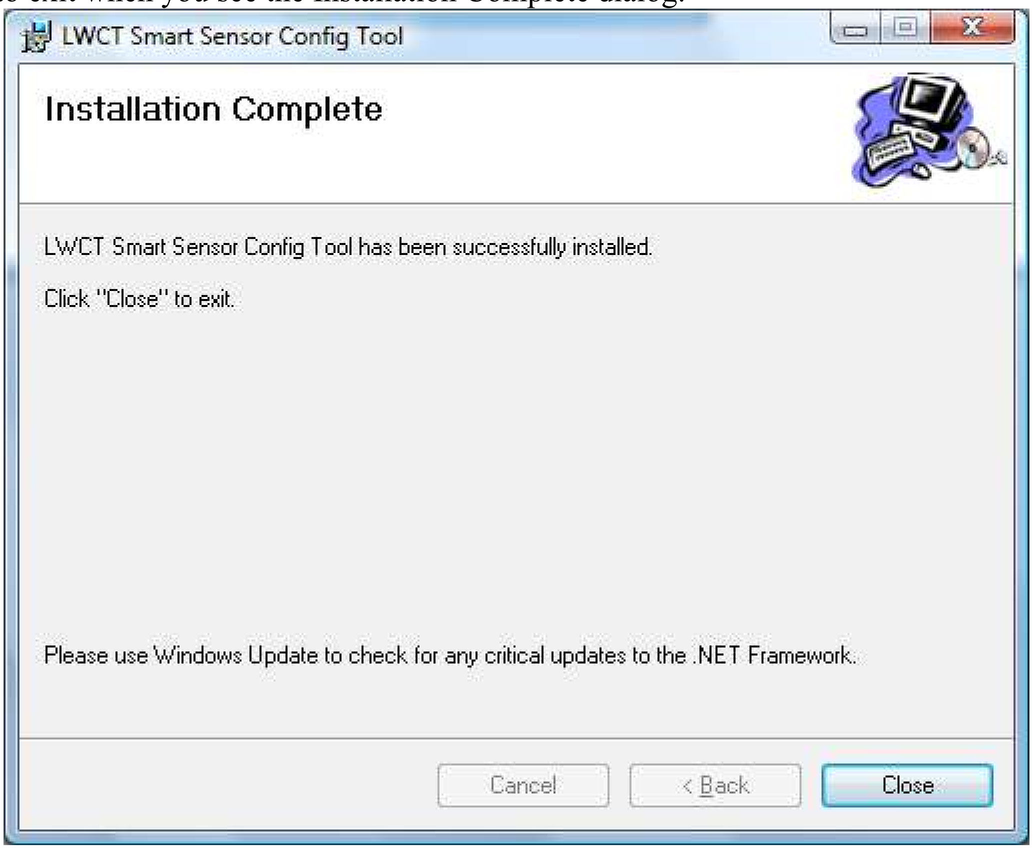
Wait until the installation is finished as shown here:



If you are using Windows XP or Windows Vista you will receive the following message notifying you that you can attach your USB to 1-Wire adapter anytime after the installation has finished. Click **OK** to complete installation:

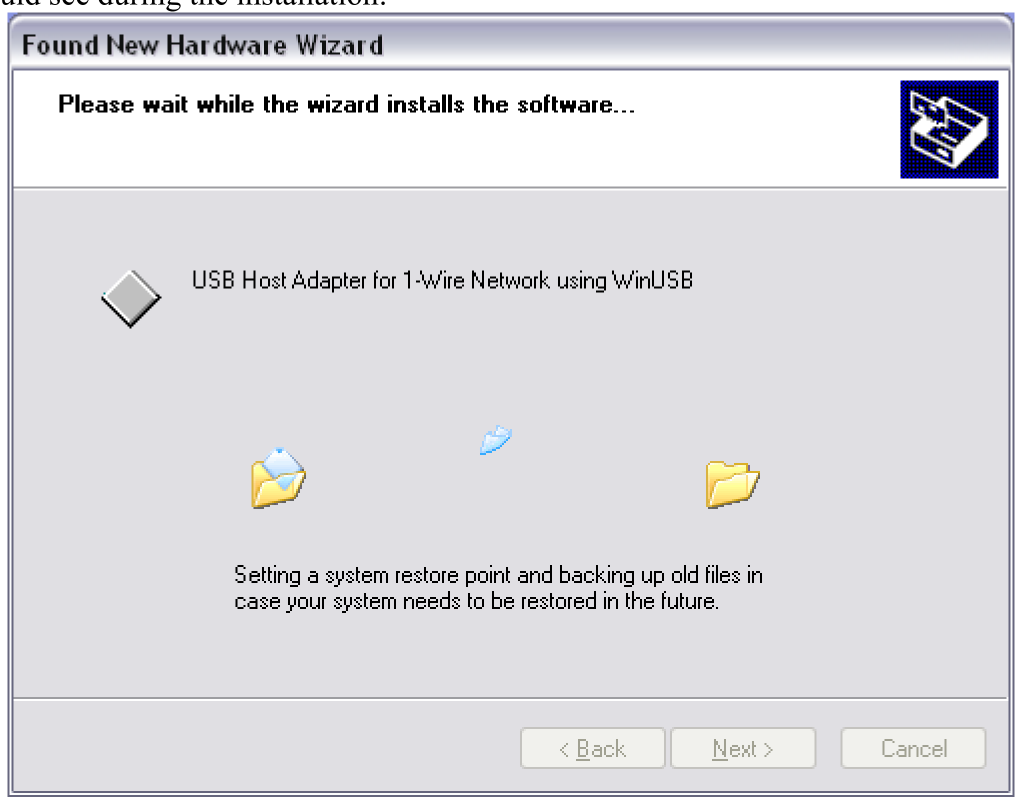


Click **Close** to exit when you see the Installation Complete dialog:

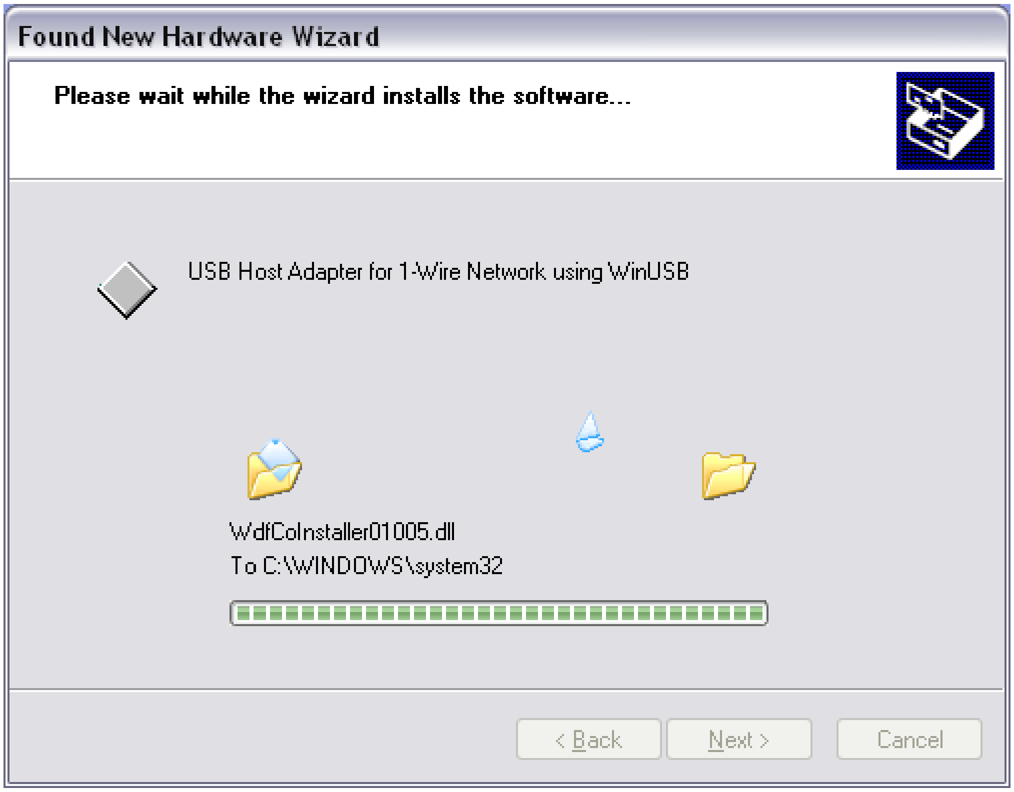


The USB Driver Setup for the USB to 1-Wire adapter is for Windows XP and Windows Vista only. When you insert the adapter into a USB port you will see the following and should click **Next** with the "Install the software automatically" option:

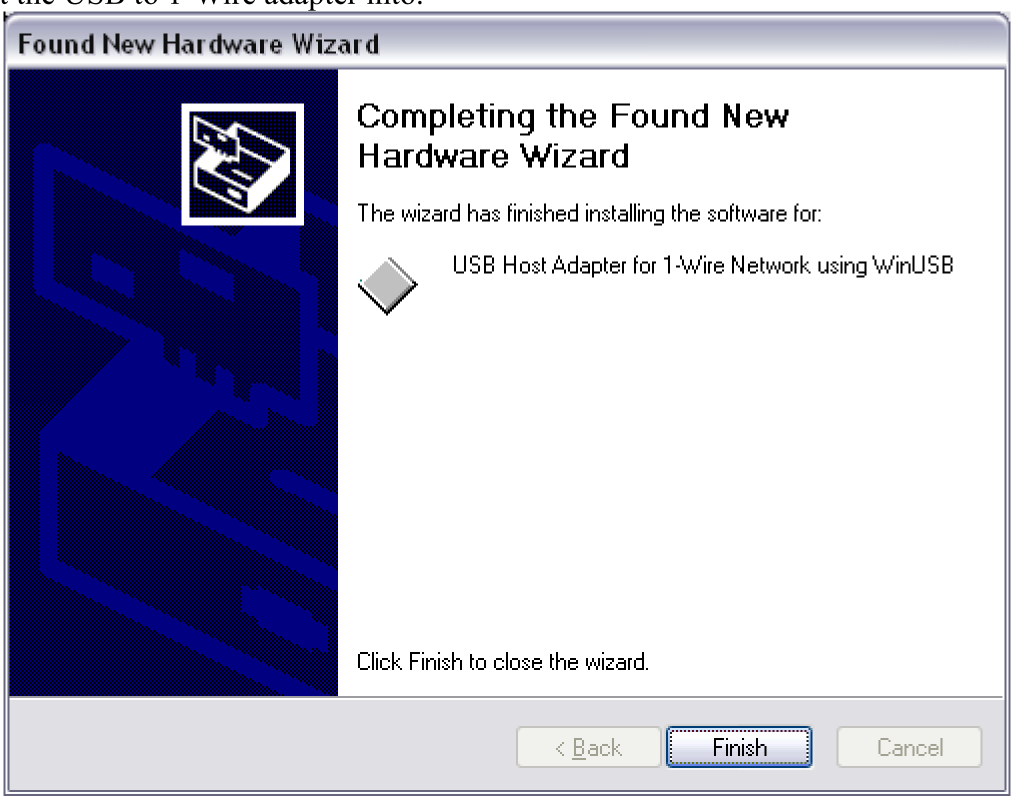
Please wait for the USB drivers to be installed. It can take a couple of minutes. Below are examples of what you should see during the installation:



2nd example display during USB driver installation:



Click **Finish** when the installation is complete. Note: this installation occurs once for each new USB port that you insert the USB to 1-Wire adapter into.



Notes:

Notes: