

Calibration Of Torque Measurements Using Strain Gages, Torque Telemetry, And Data Acquisition Systems

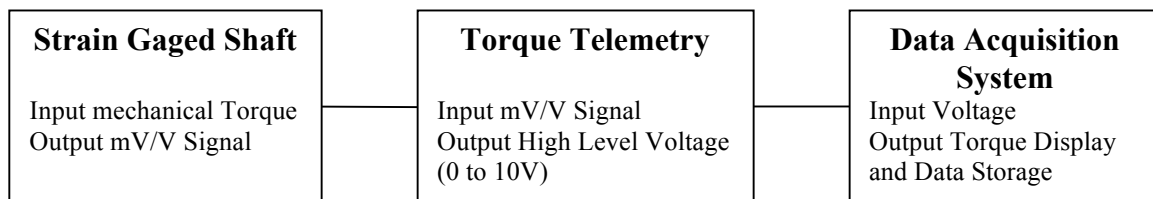
Calibration of Torque Measurements using Strain Gages, Torque Telemetry, and Data Acquisition Systems

Industry: All

Product: AT-5000 EasyApp, AT-4400, AT-4500 EasyApp, AT-7000, AT-7600

Parameters measured: Torque

This application note provides information regarding the calibration of torque measurements using strain gages, digital torque telemetry, and data acquisition systems. The intent is to provide a better understanding of how to obtain dependable torque measurements by measuring torque via strain gages and digital rotor telemetry; wirelessly transferring the signal off shaft; and providing the reconstructed signal to data acquisition equipment for recording.



General Torque-Telemetry-Data Acquisition Block Diagram

Overview:

- 1) Apply a strain gage to the shaft, or use PCB's Load & Torque organization to do so.
- 2) Find the strain gage voltage output (in mV/volt of excitation) relationship to applied torque (or use PCB).
- 3) Determine the telemetry output (in volts) corresponding to the torque (or use PCB Load&Torque).
- 4) Enter the volts/torque engineering unit relationship into the data acquisition system, and correct for any zero offset.

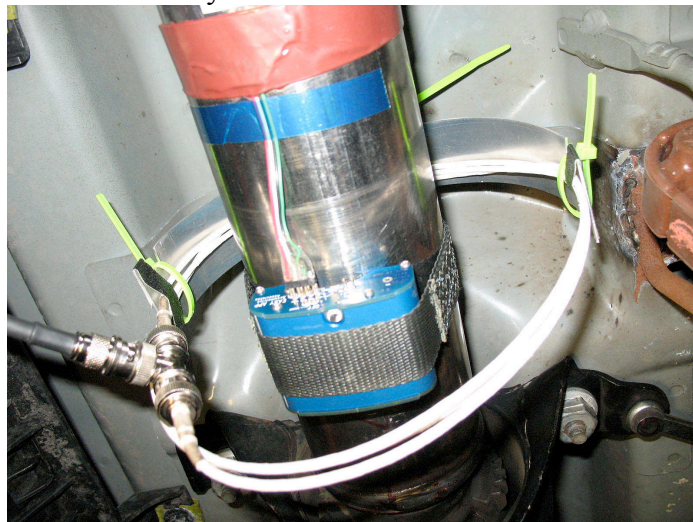


Figure 1

AT-5000 EasyApp (battery powered system) on driveshaft connected to strain gages

Strain Gages

The strain gaging and calibration of shafts can be done two different ways: either analytically or experimentally. The preferred method is by doing the calibration experimentally (physically) to obtain more precise mechanical torque to strain gage output mV/V values. For torque measurements, the strain gages are set up for a full bridge output (four resistive elements in a Wheatstone bridge configuration). Typically, strain gages have a “Gage Factor” of approximately 2, where, for instance, a 1000 microstrain stress seen in each strain gage element will cause a full bridge to put out a 2mV/V signal; a 2000 microstrain stress would cause a 4mV/V signal. The data sheet that comes with the manufacture of each strain gage will specify the specific gage factor value.

1. Experimental method:

During the operation of strain gaging and calibration of shafts data should be recorded for torque vs. output mV/V (see example of data below). In the calibration sheet below (Figure 2), a 10 point calibration curve is shown for a specific shaft that displays the applied torque relationship (microstrain) to the mV/V output. This data is produced by a dead weight physical calibration using multiple weights. In an experimental method, the gage factor does not need to be known. (See PCB Load & Torque, Farmington Hills, MI)

2. Analytical method:

If you cannot determine the torque to strain gage output values experimentally, the following equation will allow you to find it analytically. The accuracy of this method is limited to the knowledge of the materials and dimensions:

$$\text{mV/V} = \text{strain per gage} / (\text{gage factor} * 250)$$

Or, in other words, Full bridge strain gage output (in mV/V) = Strain per gage (in microstrain)/(gage factor *250). For a typical gage factor of 2 for a full bridge (4 gages), this becomes approximately: **mV/V = Strain per gage/ 500.**

Strain per gage is determined by the metal shear properties, the torque, and the shaft diameters, as follows:

$$\text{Strain per gage} = (8 * T * OD * 1000000) / (PI * G * (OD^4 - ID^4))$$

Where

PI = 3.14159

T = Torque (in-lbs or Nm)

OD = Outer Diameter (inches or meters)

G = Shear Modulus (PSI or Pa: a typical value used for steel is 1.15E7 PSI or 7.93E10 Pa)

ID = Inner Diameter (inches or meters)

A note on “mV/V” specification meaning: When a strain gage is specified with a 2mV/V output (or some other similar value), this is the millivolt output of the strain gage corresponding to a 1 volt excitation to the resistive bridge (mV/Vexcitation). If

the strain gage happens to output 2 mV/V, and the voltage applied to the strain gage is 3.3 volts, then the strain gage output voltage is 6.6 mV. Accumetrics' telemetry input amplifiers are ratiometric, meaning that they compensate for the applied voltage to the bridge (which is important for battery powered applications, but useful for induction powered applications as well), so only the mV/V value is important; the absolute value of the excitation voltage to the bridge is not important).

Shunt Calibration:

The shunt calibration resistor simulates a torque/strain on the shaft by altering the strain gage output when the resistor is remotely connected in parallel across one of the four strain gage resistor legs. When a shunt cal resistor is applied, it causes a known strain gage output voltage.

Looking at the calibration sheet below, it can be seen that a 600 Newton-meter output corresponds to 1.293mV/Volt for this specific shaft. Also, a 100 k Ω resistor Shunt Cal is shown to correspond to a 0.872mV/volt output. Using a ratio of $(.872/1.293)*600$ yields an offset of 405 Newton-meters when the 100kohm resistor is applied. In other words, the 100kohm shunt cal resistor simulates a torque of 405 N-m.

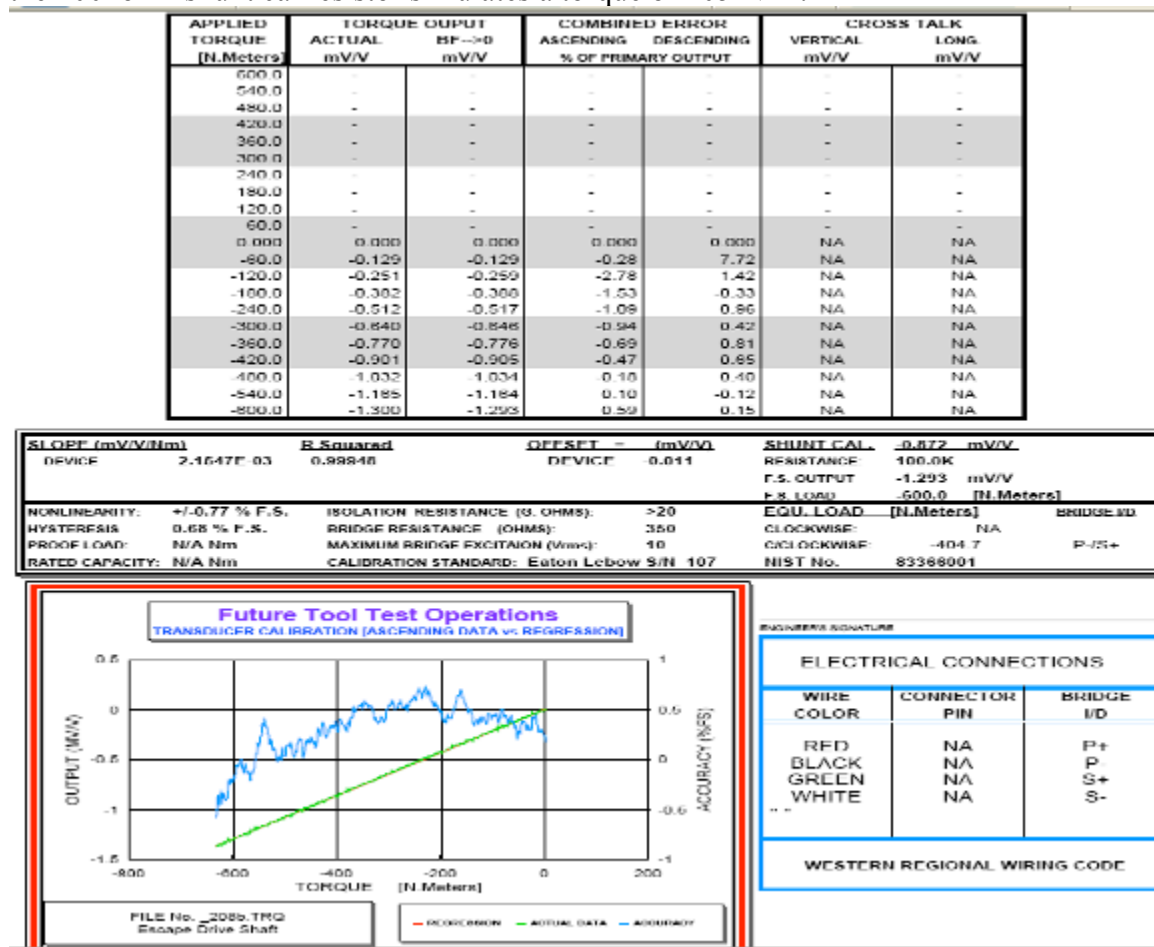


Figure 2

Digital Telemetry

A digital telemetry system simply acts as a wireless amplifier of the strain gage signal. On rotor, it amplifies and filters the strain gage signal, digitizes the data, and transmits the data wirelessly to the pick-up loop. Off rotor, the receiver converts the data to an amplified analog output signal.

The Full Scale input (gain setting) of the telemetry transmitter should always exceed the Full Scale output expected from the strain gage. (Note: If the input signal is too large, it is possible to lose the higher amplitude portion of the signal (clipping). A clipped signal will not supply useful information on signals beyond the Full Scale input limits of the transmitter.) A voltage divider resistor network can be used to decrease a large amplitude signal.

Gain setting varies for different telemetry systems; some systems have fixed factory set gains—the following applies to the AT-5000 EasyApp:

AT-5000 EasyApp gain setting is done via a resistor on the EasyApp housing (see AT-5000 User Manual, or contact Accumetrics for a list of gain selection resistor values). For other systems, contact us for gain range settings. In Figure 3 below, the full scale can be seen to be 3.37mV/V, which corresponds to a full scale receiver output. Nominally the full scale receiver output is +/-10Volts, but this is adjustable (for instance, via the P1 potentiometer inside the receiver of an AT-5000. The P2 pot sets the zero value.)

TRANSMITTER	
Part Number:	BT50075
Serial Number:	1004
Transmitter Type:	☒ AT5001 Strain ☐ AT5002 Thermocouple ☐ AT5003 Voltage
Operating Channel:	☐ Channel A ☒ Channel B
Operating Temperature Range:	☒ 0 to 85°C ☐ -40°C to 125°C ☐ to

RECEIVER	
Part Number:	BT50076
Serial Number:	1004
Package Type:	☒ NEMA Enclosure ☐ Bench Top

OUTPUT HARNESS TYPE (NEMA Enclosure Only)	
☒ 120 VAC Wall Transformer Type ☐ 12VDC Power Type ☐ Connector Only	

FACTORY SETTINGS AND CALIBRATION	
Nominal Output Range:	<u>- 10 V. to + 10 V</u>
Dip Switch 1 Settings:	☒ Bipolar Mode ☐ Unipolar Mode
Dip Switch 2 Settings:	☒ Default Mode ☐ DAC Hold Mode ☐ FS Positive Mode ☐ FS Negative Mode
RF Signal Strength Threshold:	+ 4.5 V
Meter Reading Settings (Bench Top Only):	At Negative FS: At Positive FS:
Bandwidth (-3dB):	☐ Standard 1KHz

PACKAGING TYPE	
☐ V-Block ☐ Clamp-on Collar: _____ inch inside dia. ☒ Easy App™ System BT50056 SN1023 ☐ Components Only	

CALIBRATION OF INPUT RANGE	
Strain:	<u>+/- 3.37 mV/V</u>
Temperature:	N/A
Voltage:	N/A
Shunt Cal Resistor:	0Ω
Gain Resistor Installed :	1.8KΩ

CHARGE AMPLIFIER	

Figure 3—AT-5000 EasyApp configuration document

Data Acquisition System

Input range: The Data Acquisition system will have a defined input voltage range. If the inputs of the Data Acquisition system are capable of receiving a +/- 10 V signal, then no settings need to be changed on the receiver or the data acquisition. However, if the data acquisition system is not capable of handling an input voltage of +/- 10 V, then adjust the receiver output to lower the output amplifier gain to provide a maximum range of +/- 5 V max, or other appropriate value. Some receivers have dip switch settings that can simulate a transmitter full scale output; removing power from the transmitter will result in a lost signal that also causes the receiver to output either + or - 10 volts.

The next step is to find the data acquisition system's input engineering unit conversion information for a " $Y = mX + b$ " style equation, thus allowing the user to translate AT-5000 receiver output voltages to the scaled torque values to be recorded by the data acquisition system.

Set the zero torque value:

With no torque applied to the strain gage, and with the telemetry operational, a small output voltage level will typically be found on the telemetry receiver output. Set this voltage value to zero torque in the Data Acquisition system dialog (see Figure 4 below).

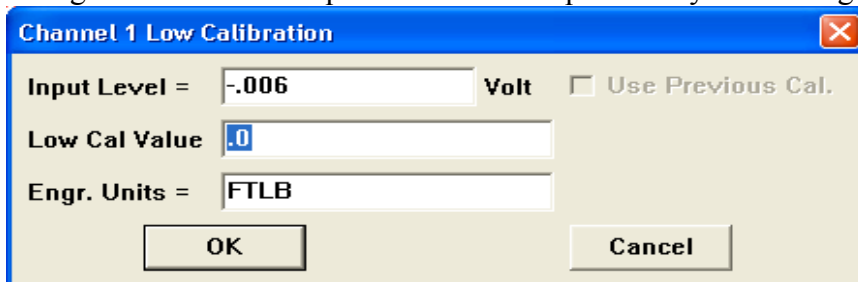


Figure 4—data acquisition units conversion dialog screen—zero torque

Set the volts to torque conversion value:

The next step is to activate the shunt cal resistor at the transmitter. The telemetry output voltage signal will now correspond to a certain change in torque value (for example: 100 K Ω resistance changes the torque by 405 Nm, which in turn causes an output voltage change of 2.43 Volts). By setting this voltage to be equivalent to the torque (in this case, 2.43 V to 405 Nm), the relationship of receiver voltage output to torque has been found.

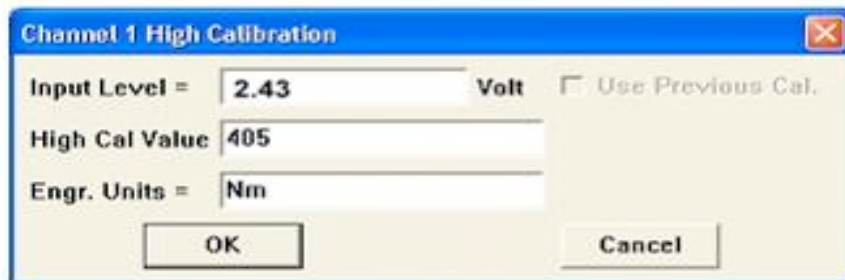


Figure 5—data acquisition units conversion dialog screen—torque to voltage

OPTIONAL-- Optimizing Transmitter Gain

The previous pages should be all that is needed to get from torque on a shaft to readings recorded by a data acquisition system. The following is information that can assist in optimizing the telemetry, if desired.

If the expected telemetry input amplifier's measurement range is very low in comparison to the maximum signal expected (i.e. perhaps less than 20% of the expected maximum signal from the strain gage), it may be sometimes be desirable to change the input amplifier gain if possible. For 16 bit high resolution systems like the AT-4400, this may not be necessary, but for the AT-5000 and for the AT-7000, this is more desirable.

For the AT-5000 EasyApp, the gain resistor on the AT-5000 transmitter housing determines the input amplifier maximum range (contact Accumetrics for a spread sheet of resistor values). It is good practice to set the gain of the transmitter above the maximum expected calibrated range in case any unforeseen 'spikes' in the signal occurs. This needs to be done if the shunt cal value is small compared to the full scale level.

An example:

If the full scale range for the telemetry input is set for 3.6 mV/V, then a strain gage output of 3.6 mV/V will cause the receiver to give a full scale output (nominally this is 10 V).

If the calibration data includes a full load applied of 600 Nm, and this shaft torque corresponds to 1.293 mV/V for a specific gage installation, then the receiver output at 600 Nm will be

$$((1.293 \text{ mV/V}) / (3.6 \text{ mV/V})) \times 10 \text{ V} = 3.59 \text{ Volts}$$

If a Shunt cal resistor of 100 K Ω causes a shift of 0.873 mV/V corresponding to 405 Nm (determined from a dead weight calibration), then

$((0.873 \text{ mV/V}) / (3.6 \text{ mV/V})) \times 10 \text{ V} = 2.43 \text{ Volts}$ for the simulated 405 Nm applied torque.

Therefore, the application of the shunt cal resistance (remotely or manually, depending on the telemetry system) causes a 405Nm output shift from its current level, which corresponds to the receiver output to shift a delta of 2.43 Volts.



What are divisions of PCB Piezotronics?

PCB Piezotronics, a member of the PCB Group families of companies, has five major divisions, all of which offer targeted sensor technologies. These divisions are supported by an active outside direct sales force of Field Application Engineers, as well as international direct sales offices throughout the world. Individual PCB Piezotronics divisions, locations and their primary product specialties include:

PCB PIEZOTRONICS^{INC.}



Depew, NY, USA - www.pcb.com – Piezoelectric, ICP®, piezoresistive & capacitive pressure, acoustic, force, torque, load, strain, shock & vibration sensors.

AEROSPACE & DEFENSE
A PCB PIEZOTRONICS DIV.



Depew, NY, USA - www.pcb.com/aerospace – Sensors & Instrumentation for aerospace & defense applications, including air and spacecraft testing.

AUTOMOTIVE SENSORS
A PCB PIEZOTRONICS DIV.



Farmington Hills, MI & Depew, NY, USA - www.pcb.com/auto – Sensors & Instrumentation for automotive testing, including modal analysis; NVH; component durability; powertrain testing; vehicle dynamics; safety and regulatory testing.

IMI SENSORS
A PCB PIEZOTRONICS DIV.



Depew, NY, USA - www.imi-sensors.com – Industrial vibration sensors, bearing fault detectors, mechanical vibration switches, panel meters, cables & accessories for predictive maintenance and equipment protection. Also providing pressure sensors and accelerometers for precision measurement requirements in the power generation and energy industries

LARSON DAVIS
A PCB PIEZOTRONICS DIV.



Farmington Hills, MI & Provo, UT, USA www.larsondavis.com – Precision microphones, sound level meters, noise dosimeters, audiometric calibration systems.

PCB LOAD & TORQUE
A PCB PIEZOTRONICS DIV.



Farmington Hills, MI, USA - www.pcb.com/loadandtorque – High quality, precision load cells, wheel force transducers, torque transducers, telemetry systems, and fastener torque-tension test systems.

ACCUMETRICS^{INC.}
A PCB GROUP COMPANY

409 Front Street, Schenectady NY 12305 USA

Phone 518-393-2200 ■ Fax 716-684-0987

Email telemetry@pcb.com ■ Website www.accumetrix.com