Tension Sensors

Basic Principles

And

Application Design Considerations

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A load cell transducer is typically made from a machined metal spring element. When compression or tension forces are applied to the spring element a strain is placed on the metal. Strain gages are bonded to the metal spring element. These gages are connected to an electric circuit that is capable of measuring the changes in resistance that occur corresponding to the amount of strain. As the strain forces increase or decrease on the spring element the corresponding resistance changes are predictable and repeatable. The strain gage electrical circuit consists of 4 precision resistors bonded to the metal and configured as a Wheatstone bridge. An excitation voltage of 5 to 10 volts is applied to one side of the bridge. The opposite side of the bridge will output a millivolt level signal that changes as the beam stress level changes. The output of the bridge circuit is typically expressed as mV/V or millivolts per volt of excitation. Most strain gage load cell transducers are constructed to output a signal of 1, 2 or 3 mV/V at its maximum stress level. Therefore a 1 mV/V transducer with 10 volts excitation will output 10 millivolts at its maximum stress point.
In figure 1 above the tension sensor has a 3 roller face plate with 2 fixed guide rollers, 1 on either side of the strain gaged tension sensor roller. The 2 fixed rollers create a fixed angle for the wire as it moves over the sensor roller. The fixed angles create a force that can be measured by the sensor. Because angles $a_1$ and $a_2$ are fixed there is a constant relationship between the tension in the wire and the created downward force. These 2 fixed points are required to create an accurate and repeatable tension sensor system.

In figure 2 above the tension sensor does not have a face plate. A single roller is attached to the sensor. The 2 fixed rollers shown are attached to the machine frame. They can be spaced at any distance from the sensor and may be a much larger diameter than what would fit on a face plate. The placement of the 2 fixed rollers must however stay within specified angles of deflection ($a_1$ and $a_2$). As the angles $a_1$ and $a_2$ increase the force or load on the sensor also increases. TMI will specify a sensor tension range based on the force created by these angles. Also note the direction of force indicator mark. This mark identifies the placement of the sensor when mounting on your machine frame. Angles $a_1$ and $a_2$ should be approximately equal ideally however many sensors can be designed for unequal angles.

When ordering a single roller sensor our application engineers will need to know your intended material path angles.

The sensor may be mounted in any position or orientation as long as the direction of force is maintained.
The tension sensor requires an electronic module that provides the excitation voltage and the ability to process the signal output from the sensor. The sensor signal must be calibrated to correspond to a usable measurement value such as grams or pounds tension. The sensor signal is also typically processed to output a higher level process control signal for close loop control or data acquisition. Typical output signal types would be: 0-10 vdc or 4-20 mA for tension control and RS232/485 for data acquisition. A digital panel meter will also have a display for visual observation of tension values.
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The tension sensor may be mounted in any position or orientation as long as the direction of force is maintained as shown above. The angles of deflection (a1 and a2) should be approximately equal, referenced to the sensors direction of force.
Wrap angle is the distance in degrees that the tensioned material contacts the sensor roller. TMI will typically shown this as the sum of the deflection angles \( a_1 \) and \( a_2 \). When angles \( a_1 \) and \( a_2 \) are known then the force on the sensor can be calculated to determine the tension sensors capacity.

TMI tension sensors can be designed to work with wrap angles between 30° and 180°. Most 3 roller face plate models have wrap angles of 40° to 60°.
When determining the load capacity of a tension sensor transducer the force created by the maximum rated tension must be calculated. The tension sensor measures the force created by the tension based on angles $a_1$ and $a_2$. This mechanical force is converted to an electronic signal by the transducer. This signal is calibrated by the signal conditioner and will display the actual tension value that corresponds to the signal. The sensors signal will be linear and therefore the tension display throughout the tension sensors range.

The actual tension force for the figure above would be calculated as:

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\text{Calculation:} \quad F = t_1 (\sin a_1) + t_2 (\sin a_2)
\]

\[
\begin{align*}
\text{Known Values} & : \\
\text{MAXIMUM TENSION} & = 1000 \text{ grams} \\
\text{WRAP ANGLE} & = (a_1 + a_2) = 50^\circ \\
\text{ANGLE} a_1 & = 25^\circ \quad t_1 = 1000 \text{ g} \\
\text{ANGLE} a_2 & = 25^\circ \quad t_2 = 1000 \text{ g}
\end{align*}
\]

The force calculation above is done for each sensor application by TMI. Our tension sensors will be rated for their full scale tension capacity. It is important to understand the above information when using the sensor in the field. A single roller sensor will have a label stating its full-scale value at a specific wrap angle. If deviating from the rated wrap angle by more than 10° consult with TMI. If the wrap angle is reduced the force will be lower and therefore the output signal, if increased it will exceed the Full Scale Capacity Rating of the sensor.

As an example the tension to force value for the above figure at different wrap angles would be:

- WRAP ANGLE = 30°  FORCE WOULD = 518 GRAMS
- WRAP ANGLE = 60°  FORCE WOULD = 1000 GRAMS
- WRAP ANGLE = 90°  FORCE WOULD = 1414 GRAMS
- WRAP ANGLE = 180°  FORCE WOULD = 2000 GRAMS
**TENSION SENSOR WITH 3 ROLLER FACE PLATE**

- COMPLETE TENSION SENSOR AS 1 UNIT
- ROLLER ALIGNMENT AND WRAP ANGLE SET BY FACE PLATE
- SENSOR CAN BE CALIBRATED BEFORE INSTALLATION
- CAN BE MOVED TO DIFFERENT LOCATIONS

**SINGLE ROLLER TENSION SENSOR**

- REQUIRES 2 ADDITIONAL ROLLERS TO BE ALIGNED AND MOUNTED TO MACHINE FRAME
- MUST DETERMINE ROLLER POSITION AND WRAP ANGLE CREATED
- NOT LIMITED TO SPACING LIMITATIONS OF FACE PLATE - ROLLERS CAN BE SPREAD OUT
- LARGER DIAMETER ROLLERS CAN BE USED
- EASIER TO THREAD MATERIAL THROUGH THE MATERIAL PATH
- USE OF ROLLERS ALREADY EXISTING ON THE MACHINE
- SENSOR MUST BE CALIBRATED IN-SITU AFTER INSTALLATION

SHOWN ABOVE ARE SOME OF THE CONSIDERATION WHEN DECIDING THE STYLE OF SENSOR TO BE USED IN YOUR APPLICATION.

THE SINGLE ROLLER SENSOR DOES REQUIRE THE 2 FIXED ROLLER AS SHOWN. PAYOFFS TAKEUPS OR DANCER ARM ROLLERS DO NOT MAKE GOOD FIXED POINTS AS THEIR DIAMETER IS CHANGING OR POSITION IS CHANGING. THIS GREATLY EFFECT THE ACCURACY OF THE SENSOR.

**FIGURE 10**

3 ROLLER FACE PLATE OR SINGLE ROLLER SENSOR
For the most accurate sensor calibration it is recommended that an actual field calibration be done. The tension sensor must be mounted in its operational position with the material contact element (roller, shaft, etc.) installed. A known accurate weight equal to between 50% - 100% of the rated full scale capacity of the sensor is required.

The following steps describe how to calibrate a TMI tension sensor with a digital strain gage signal conditioner/Indicator. If you are using an indicator supplied by TMI specific instructions have been supplied. If you are using a signal conditioner/Indicator supplied by others these steps will help relate the theory of calibration used by most digital strain gage calibration units available.

1.) Configure the indicator with the digital value in units such as grams, pounds etc. that will equate to the No Load Output Signal and the Full Scale Output Signal.
2.) Thread the calibration material through your material path and determine the output signal in mV with No Load. This value can typically be measured and stored in memory by the digital indicator.
3.) Hang the full scale calibration weight as shown in the illustration above. The output by the sensor is now the Full Scale Output Signal and should be measured and stored by the Indicator.
4.) The 2 calibration signal output points are now used by the indicator to create a signal span that can be related to the corresponding digital display values for No Load and Full Scale. This calibration slope is used by the digital indicator to calculate the correct display value for a specific output signal created by a change in the material tension.
5.) The tension sensor has now been calibrated to measure the tension in your material with the variables of mounting orientation and material wrap angles taken into account.
TYPICAL SIGNAL OUTPUT CHARACTERISTICS
OF 1 mV/V FULL SCALE RATED TENSION SENSOR

FULL SCALE OUTPUT
+10.8 mV (1.08 mV/V)

CALIBRATION SLOPE

NO LOAD OUTPUT
+7 mV (0.07 mV/V)

TYPICAL SENSOR OUTPUT IN MV
(10 VDC EXCITATION)

FIGURE 12

DEFINITIONS

NO LOAD OUTPUT: Output signal from sensor after installation with rollers, shafts and hardware installed.

FULL SCALE OUTPUT: Output signal from sensor after tensioned material threaded through rollers and calibration weight equal to full scale tension capacity hung at end of material.

MILLIVOLT PER VOLT: Output in millivolts per volt of excitation (mV/V)

SIGNAL SPAN: The algebraic difference between the output signal at full scale and the signal at no load.

MATERIAL TENSION: Longitudinal tension applied to material traveling between points in a material process path.

SENSOR FORCE: Force created at a fixed point by the tensioned material when the material path is deflected by fixed angles on either side of the tension sensor force axis.

WRAP ANGLE: The sum of the deflection angles of the material path on either side of the sensor force axis.