Automatic In-Die Part Quality Monitoring &Tool Adjustments

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Goals

- Determine appropriate sensors for in-die applications.
- Apply the sensors to make critical part measurements.
- Track parts through the process.
- Take different actions based on the status of the parts we are tracking.
- Avoid unnecessary stops. Keep the press running!
- Make all this usable without extensive training requirements.

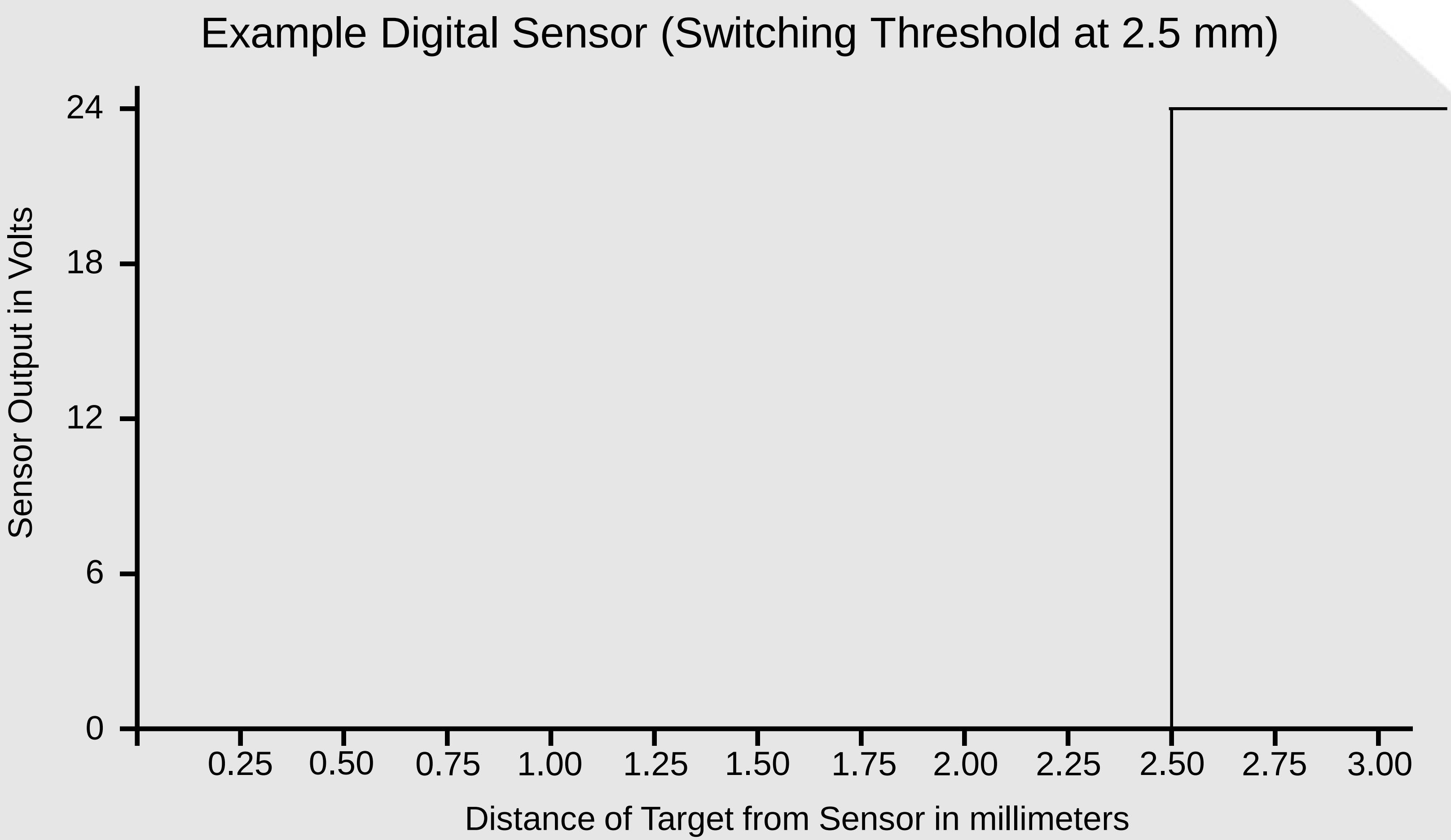
Process Visibility

- Before we can control anything, we need visibility into the process.
- We mostly rely on sensors to give us this visibility.
- The proper selection and application of sensors is critical if we are to succeed in gaining the benefits we would like.

Digital Sensors

- Digital sensors generally switch between 2 different values (on or off, open or closed, etc) when whatever triggers them crosses some threshold value.
- As an example, steel crossing the sensing field of a traditional NPN output inductive sensor will cause the sensor to pull its output to ground.
- Digital sensors as used in stamping usually represent the presence or absence of something (material, a hole, a weld-nut, etc).

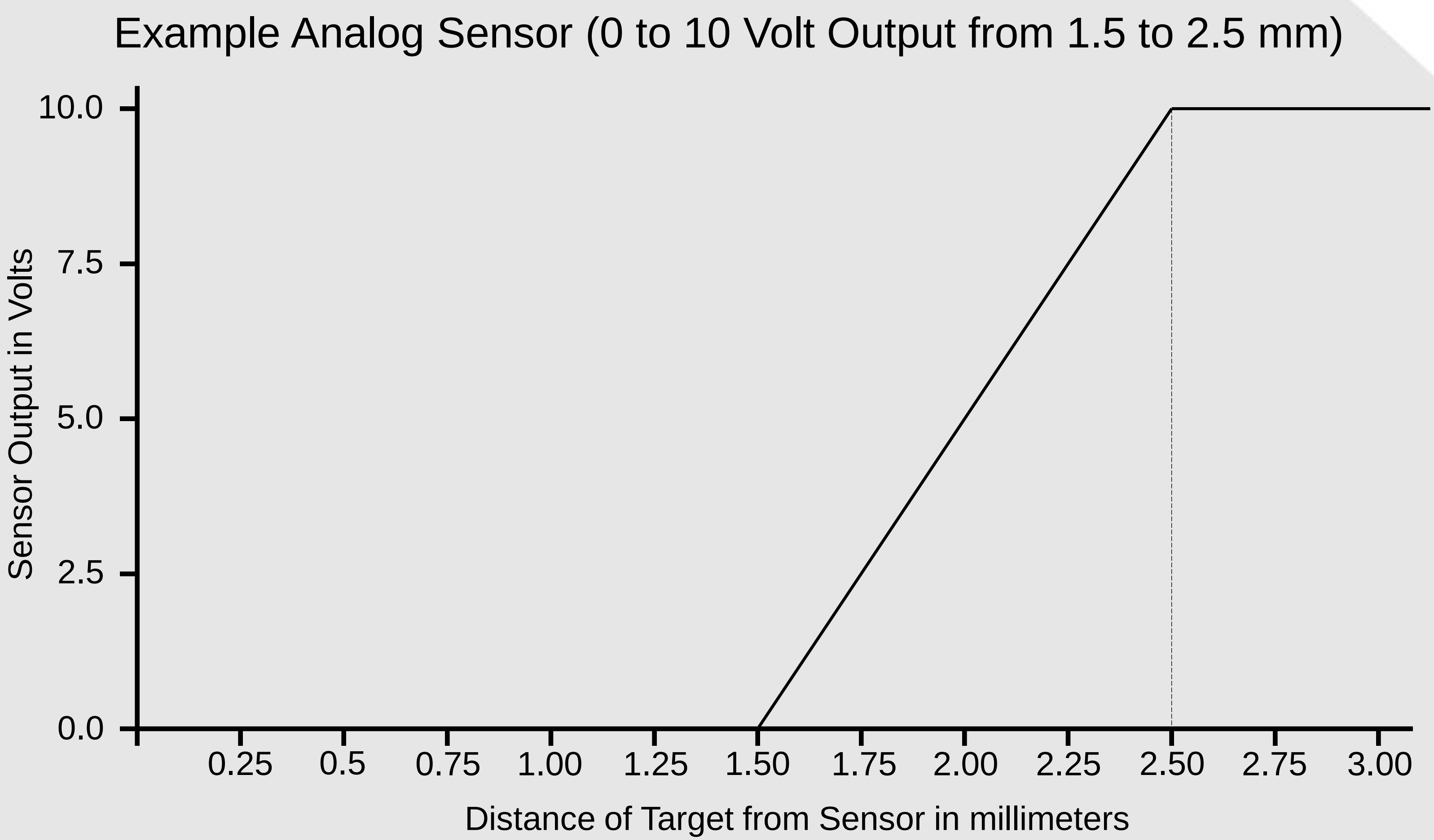
Digital Sensors



Analog Sensors

- Analog sensors output a continuous range of values in response to whatever triggers them (amount of light, distance to target, temperature, etc.)
- As an example, an analog sensor might put out 0 volts when steel is 1.5mm from the sensing face, and 10 volts when the steel is 2.5mm away. The voltage will vary linearly between those values depending on where the steel is.

Analog Sensors



Analog Sensors

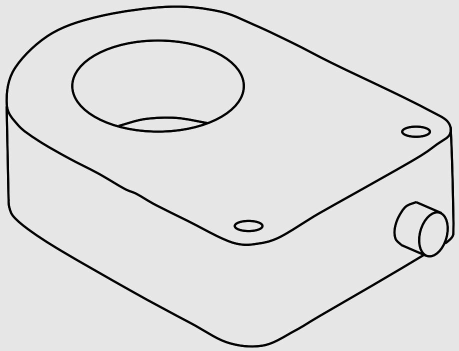
- Analog sensors can be used to measure a part dimension or property.
- This could be length, width, thickness, bend angle, hardness, hole diameter, or any other property for which we can find a sensor and successfully apply it.
- Note that this does NOT do away with the use of digital sensors, but analog sensors allow us to gain some unique capabilities.

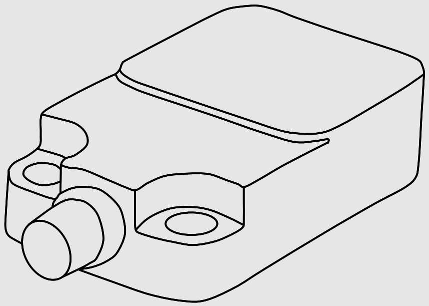
Sensor Improvements

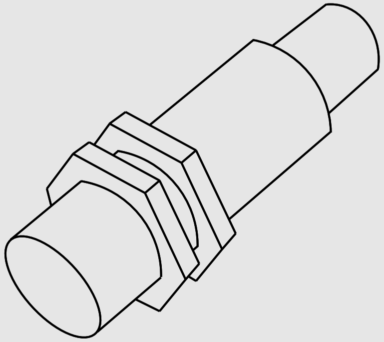
- Sensors have been ruggedized and in some cases specifically targeted at in-die applications.
- Sensors are now available in extremely small sizes, some inductive sensors go down to 3mm in diameter.
- There has been an explosion of form factors that are able to meet more applications.

Sensor Types

- Inductive
  - Both digital and analog outputs available
  - Traditional cylindrical
  - Flat and/or rectangular
  - “Ring Type”

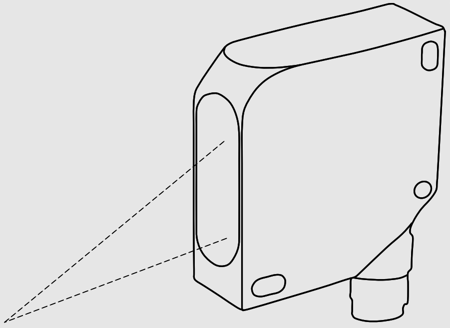


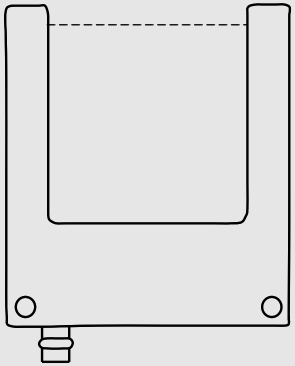


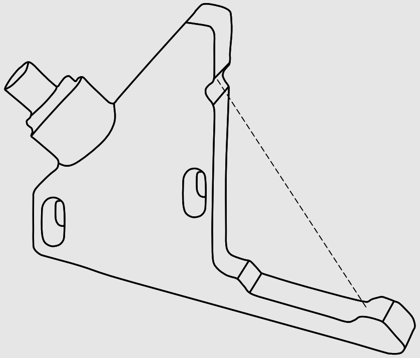


Sensor Types

- Photoelectric
  - Reflective
  - Through beam
  - Laser Triangulation
  - Slot
  - Angle
  - Window
  - Fiber optic





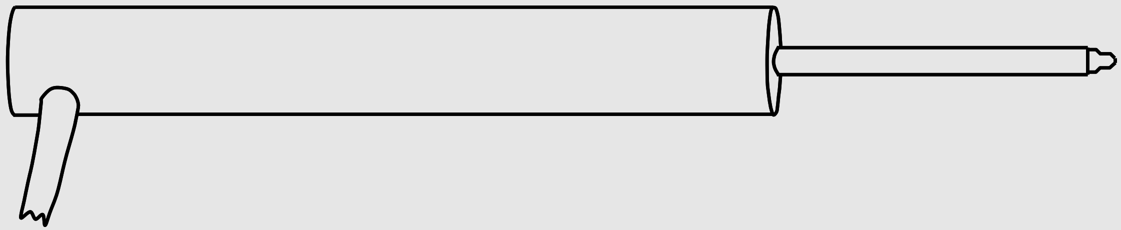


Sensor Types

- Machine vision
  - Camera and processor are separate
  - Processor integrated into camera
  - Very flexible in the kinds of measurements they make
  - Can make multiple measurements in one pass
  - Often require special lighting requirements
  - Oil mist can cause problems

Analog Sensor Pros and Cons

- LVDT (linear variable differential transformer)
  - Very accurate
  - Sub-micron resolution
  - Small
  - Durable
  - Requires separate amplifiers
  - Usually requires some kind of sequencing since they require contact with the object being measured. Often this is air activation with a spring return.
  - Relatively expensive



Analog Sensor Pros and Cons

- Inductive Analog Proximity
  - 0.0001” resolution possible
  - Barrel styles down to 4 mm
  - Flat rectangular style
  - Non-contact
  - Generally have a small sensing distance
  - Lower cost
  - Very durable
  - In most cases the datasheet specifications of the these devices are based on a certain size, thickness, and material of the target. A typical example would be mild steel at least 1mm thick and slightly larger than the sensing area of the sensor.

Analog Sensor Pros and Cons

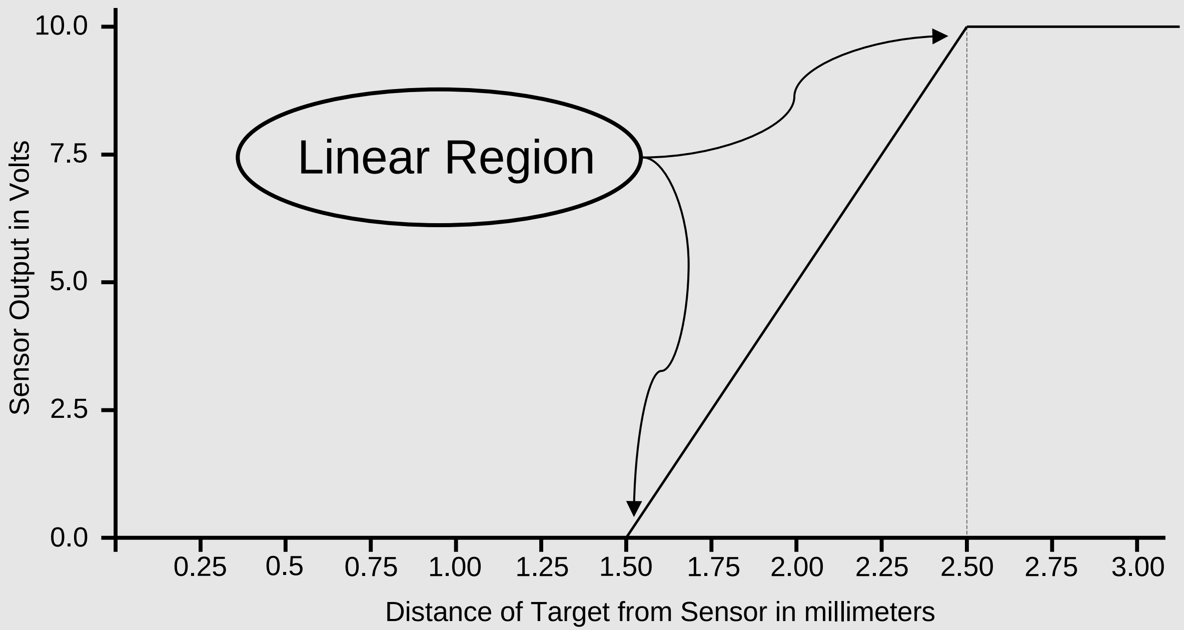
- Laser triangulation sensors
  - Longer sensing distance than inductive
  - .001” resolution generally possible for lower speed applications.
  - .003” resolution generally possible for higher speed applications.
  - Non-contact
  - Possible issues with oil mist.
  - Not as durable as LVDT or inductive.
  - Higher cost.

Sensor Output Types

- We need to convert the sensor output into appropriate engineering units.
- 0 to 10 volts and 4 to 20 milliamps are common analog sensor outputs.
- You may less commonly run into -10 to 10 volts, 0 to 5 volts, and 1 to 6 volts.
- We either need to standardize on a output type (sometimes hard to do as the sensor you need next week may not be available in your output type), or select process monitoring equipment with configurable inputs that can deal with multiple sensor output types.

Sensor Calibration

- Nearly all the sensors we would use for these applications are “linear”. When plotted on a graph, the output versus input will ideally result in a straight line in the region where the sensor is specified to work.

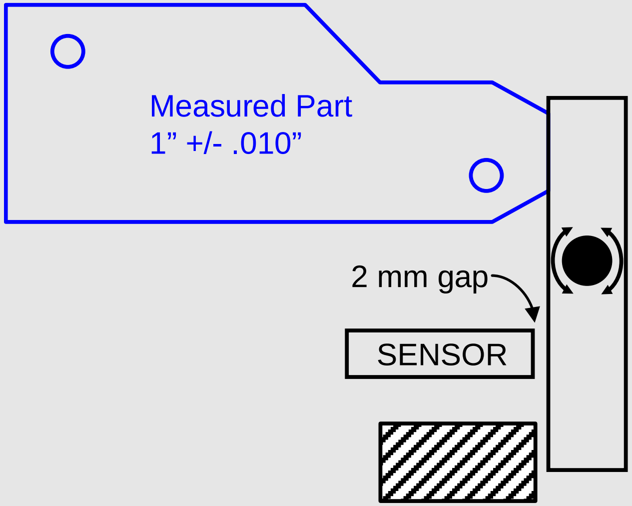


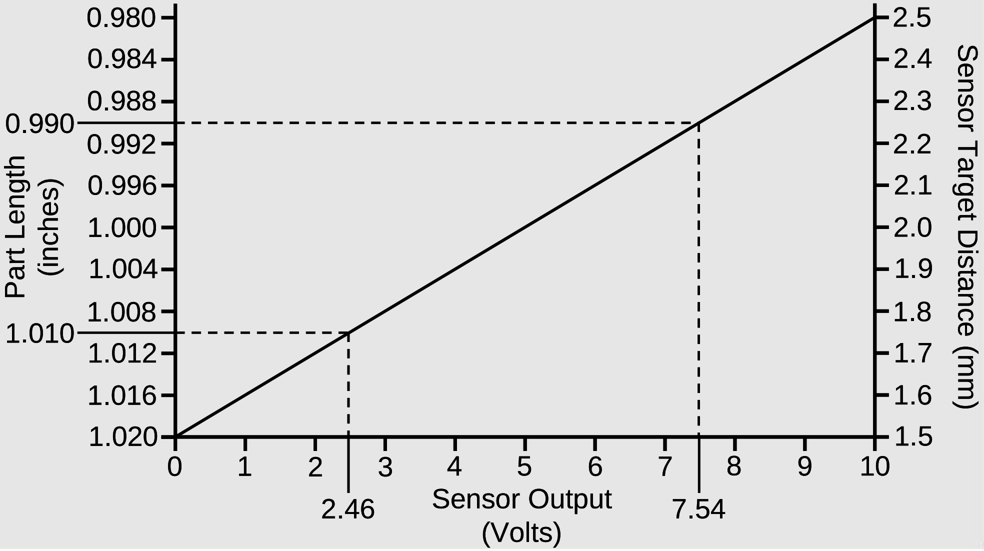
Sensor Calibration

- As we remember from high school, we need two points to describe a line. Therefore, we need to supply two measurements to convert the sensor output to the unit we want. Essentially we want a “short” part and a “long” part.
- Our example sensor works at a distance of 1.5 to 2.5 mm from the target – a span of 1 mm (or about .039 inches).
- Lets assume we have a part with a nominal length of 1.000 inches and with a +/- .010 tolerance on that dimension. The length of our example part is set by the length of the feed.

Sensor Calibration

- Our example part is “fed to length” into a rotating member that activates the sensor (providing a consistent target). We find that feed length of 0.990” results in a sensor output of 7.54 volts. A feed length of 1.010” results in a sensor output of 2.46 volts. We now have our two points. Notice the sensor is set so that a part of the correct length is in the middle of the sensing range.



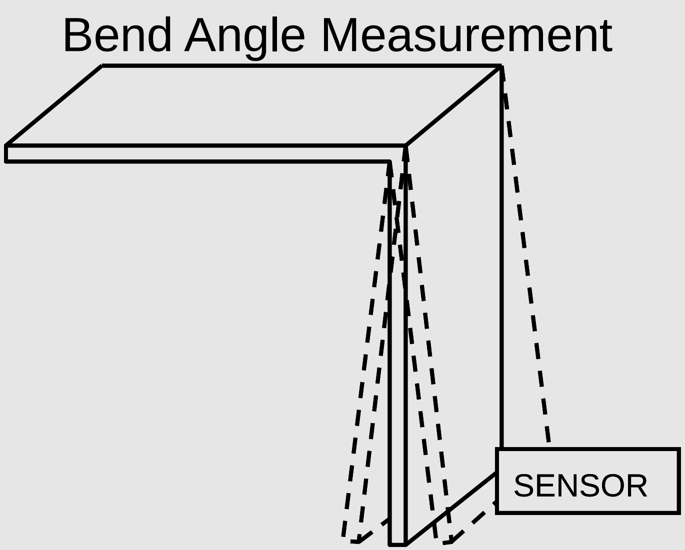


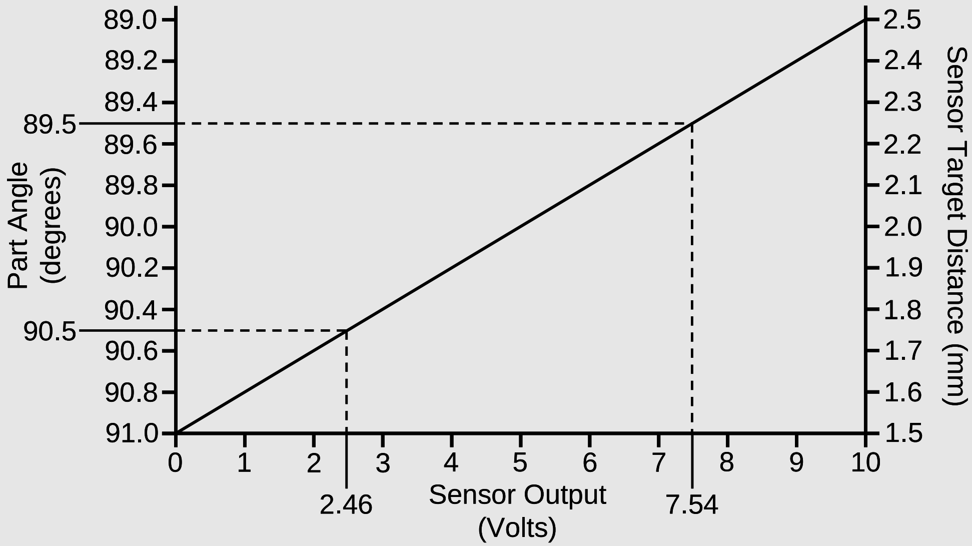
Sensor Calibration

- This calibration is stored in our monitoring equipment and becomes part of the job setup.
- At some point, we could find a different model of sensor, brand of sensor, or even a different sensor technology that works better for the application. Because we calibrated in engineering units, we can simply repeat the calibration process for the sensor and the rest of our job settings remain the same.
- Again, because we calibrated the sensor in engineering units, limits on the part dimensions can be entered in right from the part drawing or customer spec. If the tolerance were to be changed to +/- .005” at some later time, we simply key in new limits with no recalibration of the sensor needed.

Sensor Calibration

- The same two point calibration would work for the bend angle measurement example below. We need two parts, preferably at either end of the acceptable range of bend angles.
- For any measurement that we can come up with in a linear system, we need two points on the line to calibrate the sensor.





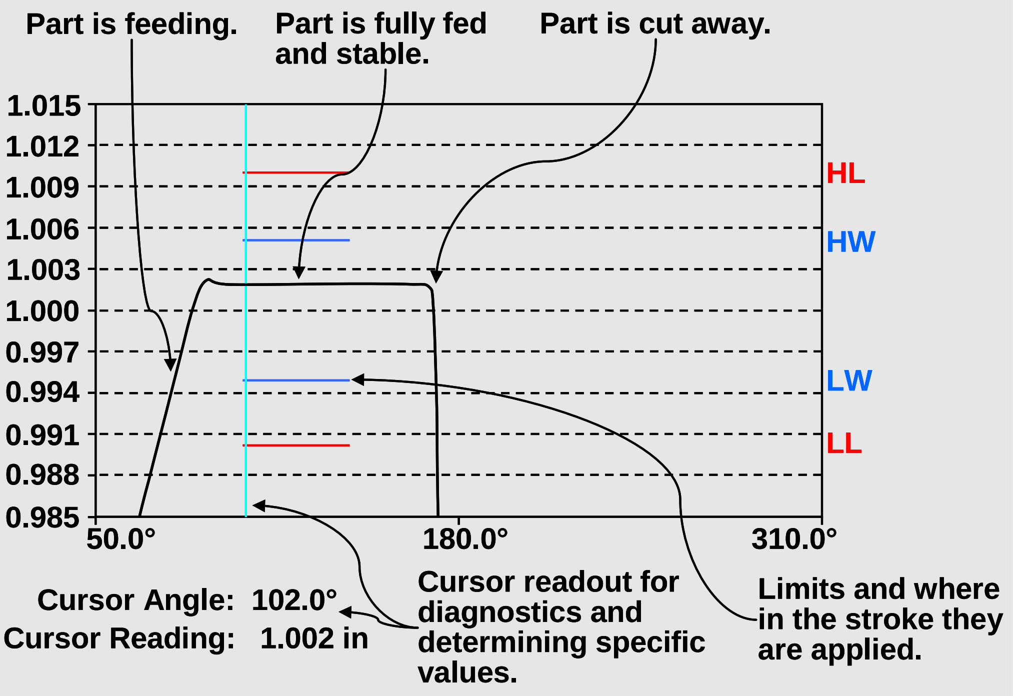
The Measurement Window

- Next, we need to determine where in the stroke we can make a good measurement.
- In our “feed to length” example, we need to measure the part after the feed has completed, but before the die cuts the part off the strip.
- In the bend angle example, we probably need to measure the angle when the part is clamped down by the die at the bottom of the stroke.
- We need to be able to “see” what the sensor “sees” throughout the stroke so we can determine stable places to take the measurements.

The Measurement Window

- The monitoring system should be able to show you the sensor graph through the stroke. Finding the appropriate place in the stroke to take the measurement then becomes fairly simple. The graph at right is what we might see in our “feed to length” example.

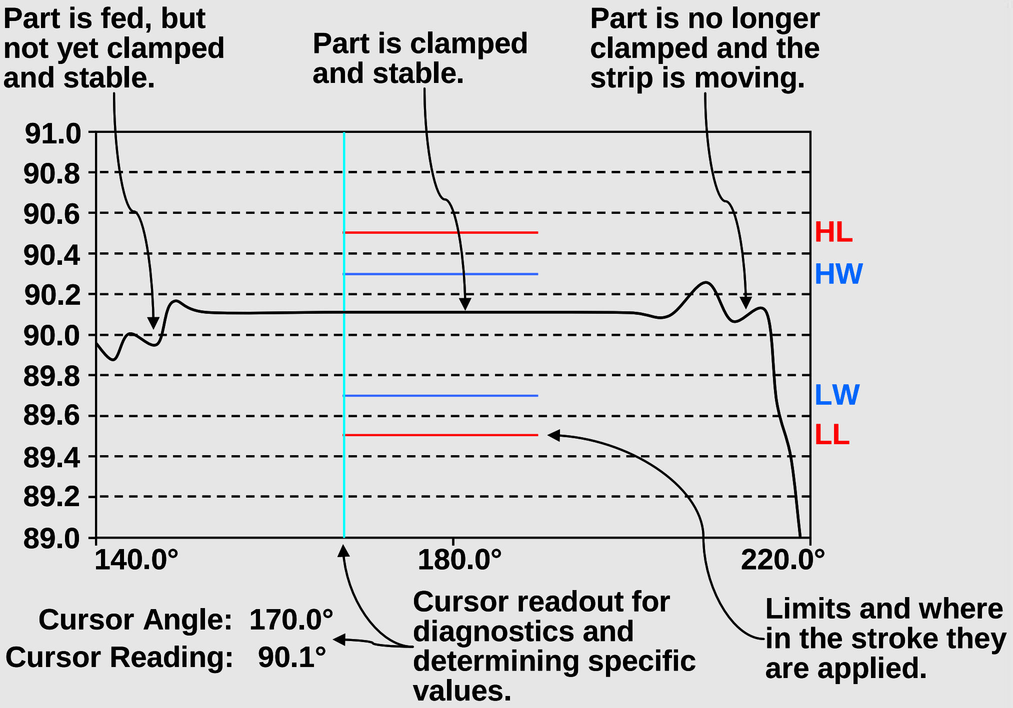
Diagnostic Graph for
“Feed to Length” Example



The Measurement Window

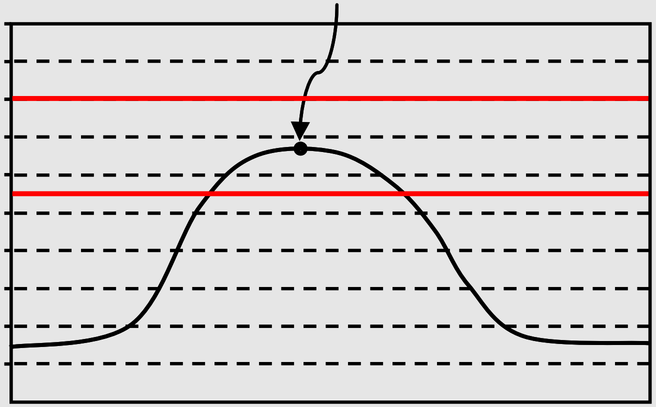
- At right is what we might see for our bend angle measurement example. Here we are “zoomed in” on the bottom of the stroke where the part will be clamped and stable. A diagnostic cursor is a handy capability for finding the specific start and stop angles (or slide heights) at which to take the measurements. The red and blue lines are the limit levels.

Diagnostic Graph for Bend Angle Example



Measurement Type

- We now have a sensor for taking a measurement, a calibration for converting that measurement to engineering units, and a “window” where we know we need to take the measurement.
- The next thing to decide is what to measure...
- Highest or “Peak” value – The highest value we captured in the measurement window must be within the limits. We might use this measurement if we were capturing a notch depth as it swept by the sensor while the strip was feeding.

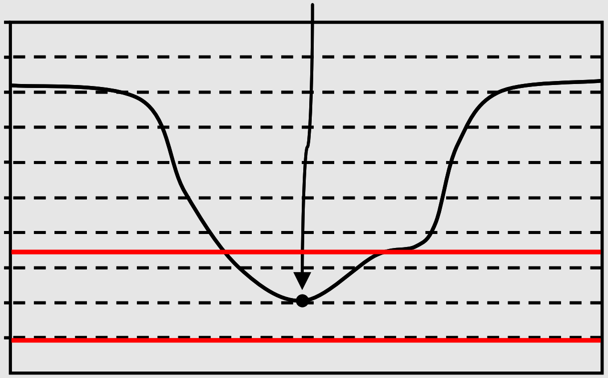


Measurement Type

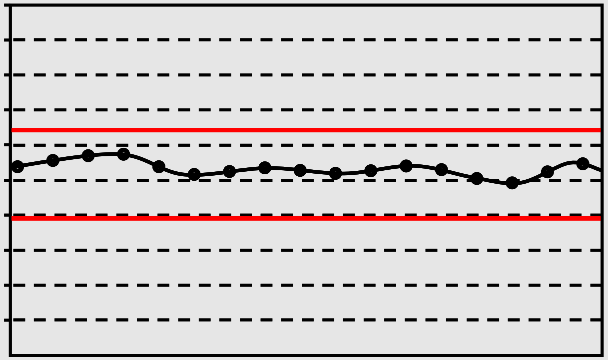
- Lowest or "Valley" value – The lowest value captured in the measurement window must be within the limits. This could be used to capture the shut height seen by the dies at the bottom of the stroke.

- Every value – every point we capture in the window must be within the limits.

Lowest (or Valley) Value

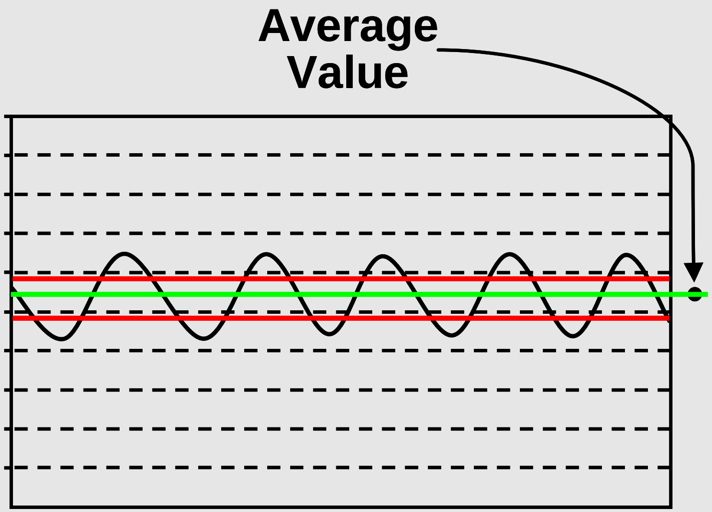


Every Value



Measurement Type

- Average value – The average value of all points captured in the measurement window must be within the limits. The graph at right has been exaggerated for effect, but the pressroom is an electrically noisy environment. Averaging multiple readings leads to more consistent measurements. In general, averaging should be used whenever possible.



Limits and Actions

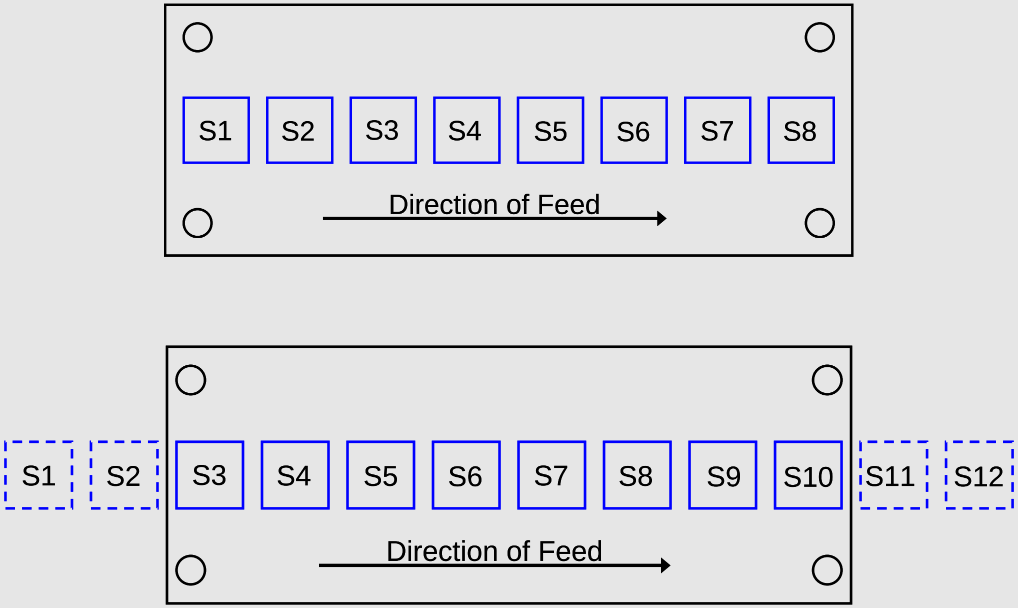
- At this point we have the ability to make a measurement at the right point in the stroke and convert it into the unit of our choice. Now we need to place limits on those measurements and decide what to do if they go outside the limits.
- High and Low Limits – Generally used to indicate the part is no longer in spec.
- High and Low Warning Limits – Generally used to indicate the part is still in spec but is starting to wander out.
- Each Limit needs an action
  - Stop the press (top or immediate)
  - Just show the status (usually for warning limits)
  - Mark the part as “Bad”
  - Adjust the die via servo motor etc.

Limits and Actions

- If our die is designed for it, we can make adjustments to the part based on the limit actions.
  - We set limit actions for the channel (usually the warning limits) for “Motor Forward” or “Motor Reverse” based on the direction that will bring the part back to the middle of the spec.
  - We tell the channel which motor to activate (there could be multiple motors).
  - The motor is set to increment a standard amount at an allowable place in the stroke every time the sensor triggers it.
  - The motor also has a stroke delay associated with it after it moves. Most of the time the motor will be one or more stations “back” in the die. The sensor will not see the change for that many strokes so we don’t want to move again until we see the result of the change.
  - The motor drive parameters for this particular setup (speed, acceleration, PID settings, etc.) are stored with the job – this lets us use the drive for multiple dies.

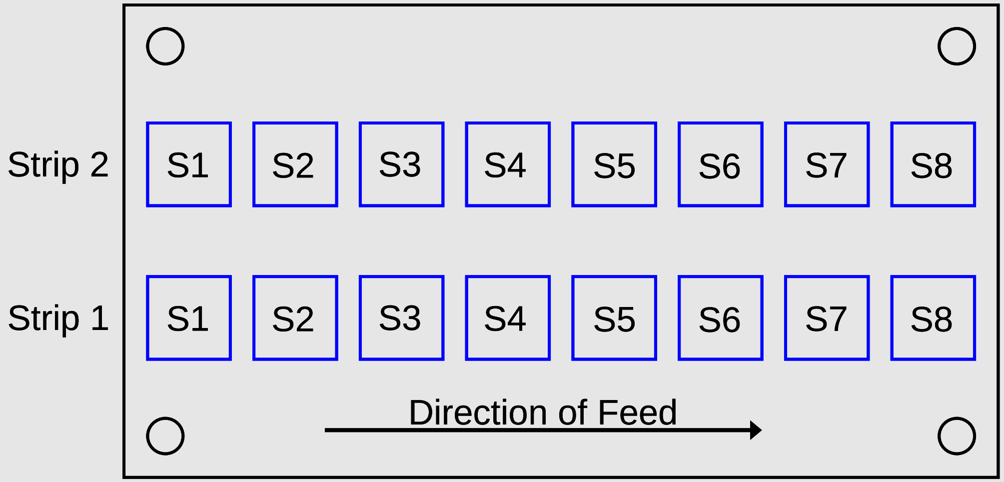
Part Tracking

- Certain of the actions we can take require that we be able to track parts through the die.
- In general, parts can be “Good”, “Bad”, or “Empty”.
- A station number is assigned to each station in the die.
- We can also assign “virtual” stations that let us synchronize measurements or operations outside of the die (such as material thickness).



Part Tracking

- For dies with multiple strips, we divide by strip and station. Instead of referring to a sensor on station 1 - it is on strip 1, station 1 or strip 2, station 1 etc.
- Each strip has its own Part counter, Batch counter, and Scrap counter which can be driven by one or more part out sensors.

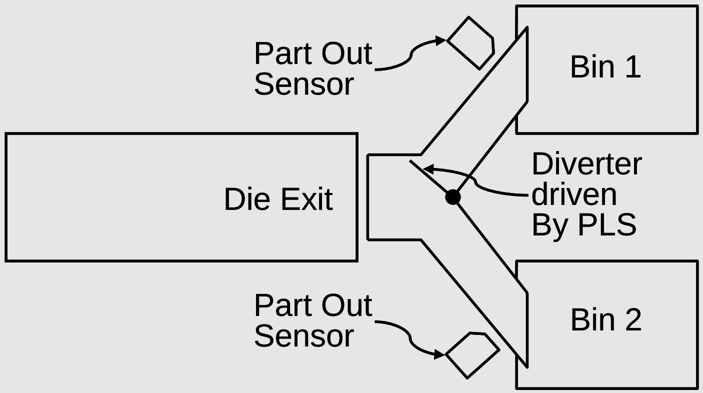


Part Tracking

- Other control system components (die protection, programmable limit switch, tonnage monitor, etc.) can act based on the status of the part.
- The status these systems act on can be …
  - “Good”
  - “Bad”
  - “Empty”
  - “Not Good”
  - “Not Bad”
  - “Not Empty”.
- Each die protection channel, analog process monitor channel, or programmable limit switch channel that will act on part tracking status is assigned a strip and station. This way the channel “knows” which part status to check or which part to mark.

Part Tracking

- Programmable Limit Switch part tracking related functions
  - Can be “fired” (or not) based on the status of the part in its station. For instance, a PLS channel can be set to fire a gagged punch to knock a part with a “Bad” status out of the strip or activate a diverter chute on the die exit to send the part to a scrap bin.
  - Can be “fired” after a set number of Part, Batch, or Scrap counts for a particular strip. When set to toggle, this lets us automatically switch a diverter to start filling a new bin without stopping the press. The filled bin is then changed so it will be ready for the next switch.



Part Tracking

- Die Protection part tracking related functions
  - Can mark a part “bad” instead of stopping the press when the channel logic is not satisfied. This allows digital die protection to check the presence or absence of some part feature (such as an in-die welded nut). It also allows external systems, (machine vision, color sensors, etc) to tie into the part tracking capabilities of the control.
  - Can bypass itself based on the part status. For instance, a DP channel monitoring a transfer finger could allow the press to keep running if the part status is “Empty” because we already diverted the part to scrap.
  - Part, Batch, or Scrap out sensors can be tied to DP channels to drive the counts. Limits can be put on those counts and/or they can drive PLS channels. Using properly applied sensors for this function results in accurate bin counts of parts and an accurate scrap count.

Part Tracking

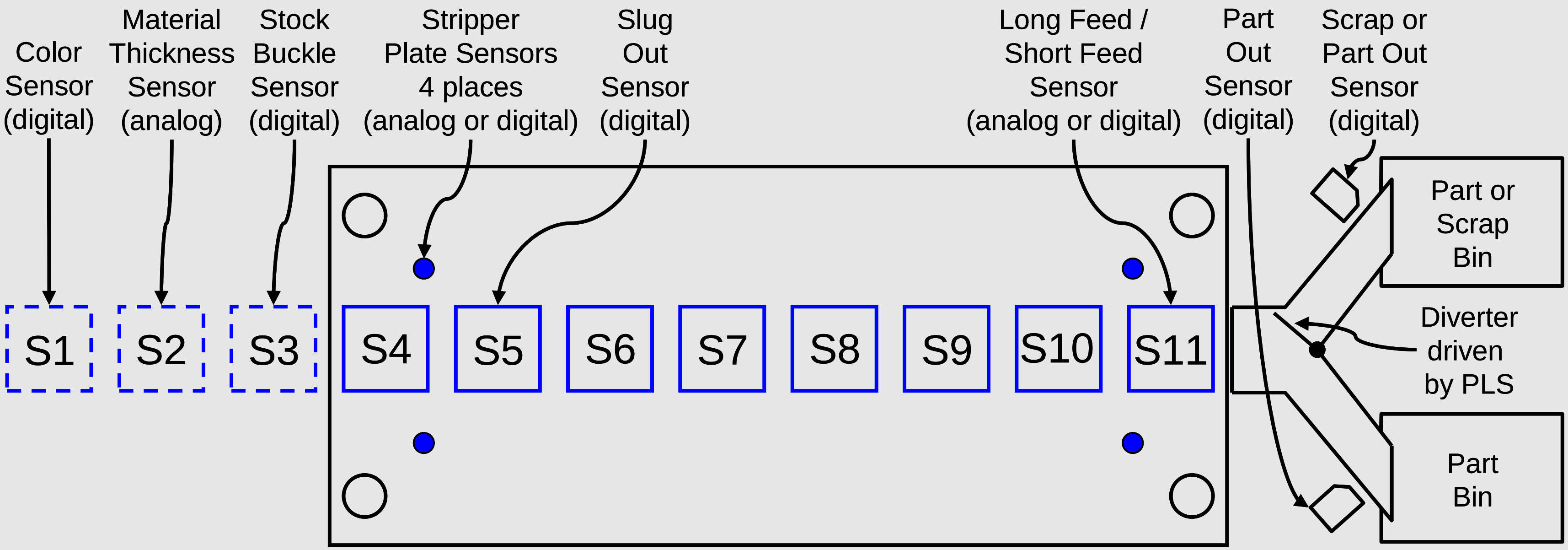
- Analog Process Monitor part tracking related functions
  - Limits can be set to mark parts as “Bad” if exceeded.
  - Note that each limit (low warning, high warning, low, and high) has its own action. For instance, a low warning limit could be set to indicate status, the low limit and high warning limit could be used to mark a part bad, and the high limit set to stop the press because of a clearance issue.
  - Can bypass itself based on the part status in its station. For instance, a sensor that would stop the press if a part so far out of spec that it will not feed through the die could bypass itself if the part was “Empty” because it was kicked out of the process earlier.
- Tonnage Monitor part tracking related functions
  - Low limits can be automatically bypassed when there is an “Empty” and/or “Bad” part in the die. Other limits remain in effect.

Part Tracking

- Counter part tracking related functions
  - Now that we can keep the press running by automatically diverting “bad” parts, there is the possibility of creating a very efficient process for making scrap – not the best outcome.
  - We need to track the amount of scrap we are making vs. the number of parts. We need some additional counter limits.
  - Counters need to track the number of bad parts in a row. We place a limit on this value and stop the press if the limit is exceeded so we can determine what has gone wrong in the process.
  - Counters need to track the number of bad parts produced in the last so many strokes (perhaps 1000). We place a limit on this value and again stop the press if it is exceeded. This counter limit prevents a situation where every other part (worst case) is bad but doesn’t trip the “bad parts in a row” limit. Ultimately, this is a limit on the scrap percentage in the last X strokes.

Simple Applications

- Many applications of this technology do NOT require extensive, or in some cases any, die rework. Some analog sensors are available in the same form factor as the digital sensors currently installed in the die.
- Other sensors can be added to the "front" or "back" of the process.

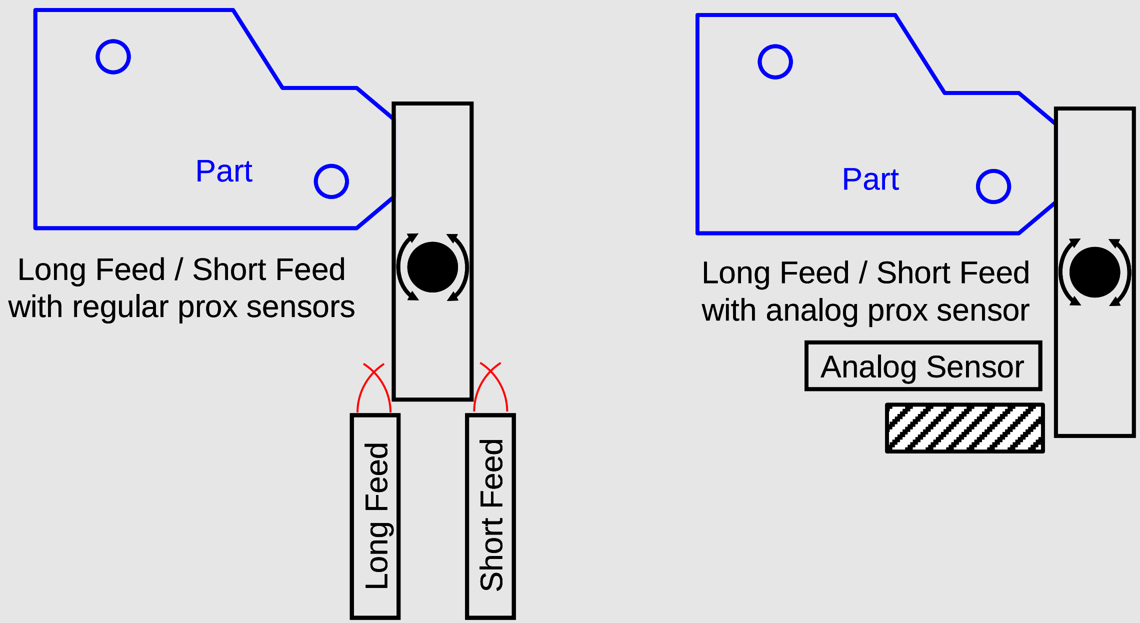


Simple Applications

- Stripper plate and long feed/short feed sensors can often be replaced with an equivalent form factor analog sensors.
- Using proximity sensors for stripper plate problem detection can be difficult to set up. There is usually a tradeoff between sensitivity and reliable operation – especially with thinner material. Using analog sensors in this application can allow resolution of better than .001” and allows programmable thresholds. This enables better detection capabilities and a more reliable process.

Simple Applications

- In some cases, two long feed/short feed proximity sensors can be replaced with one analog sensor with better accuracy and with programmable tolerance.



Simple Applications

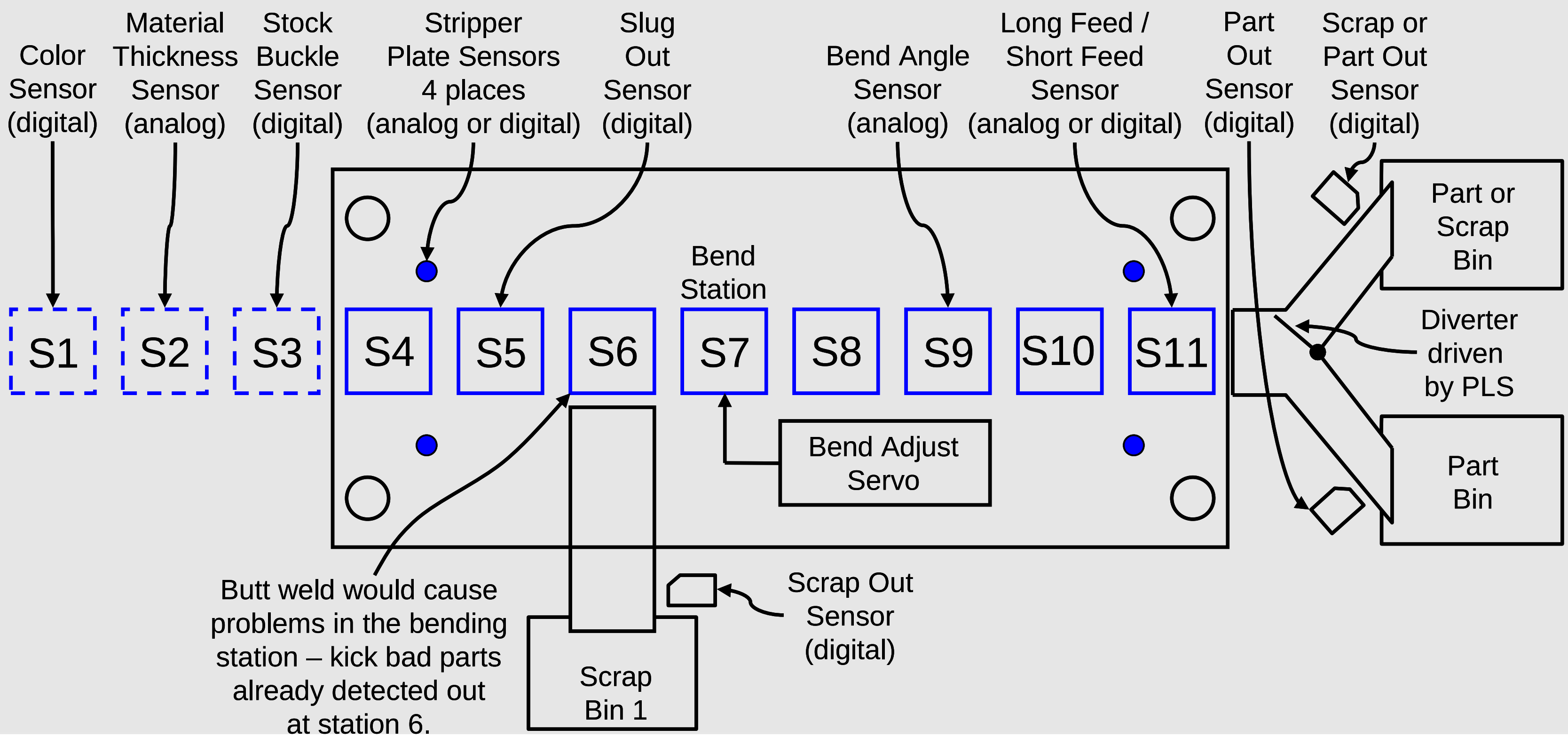
- Color sensors are available with a digital output that indicates when the sensor "sees" a particular color. A manufacturer had his service center butt weld several coils together and paint the weld area blue. The color sensor is tied into a die protection channel that marks the part "bad" and the diverter on the exit of the die rejects the parts.
- A material thickness sensor can examine the strip as it feeds into the die, marking "Bad" those areas that are out of tolerance. These parts can then be rejected as they exit the die.
- A diverter can be added to the exit side of the die and made to divert scrap to a separate scrap bin. Sensors on each bin count the parts going into each one. Accurate part and scrap counts (and therefore scrap rate) can be maintained.

Simple Applications

- Even if we don’t track parts and use no analog sensing at all, a diverter on the exit of the die can still be used to automatically switch bins every so many parts. In this case, the sensors on each bin both drive the same part count. A PLS channel is set to toggle every so many parts. The press never has to stop as long as the full bin is changed out before the other fills up.
- Instead of using a mechanical diverter, two PLS channels could be used, one firing for good parts, one for bad. Each PLS could be tied to an air blow off that would send the parts to an appropriate bin.
- Again using two PLS channels (“bad” and “good”), some other piece of automation, such as robot, could be signaled to pass the part to another piece of machinery in the process, or reject it.

Sophisticated Applications

- Getting the full advantage of analog sensors will usually require a die built to use them from the start.

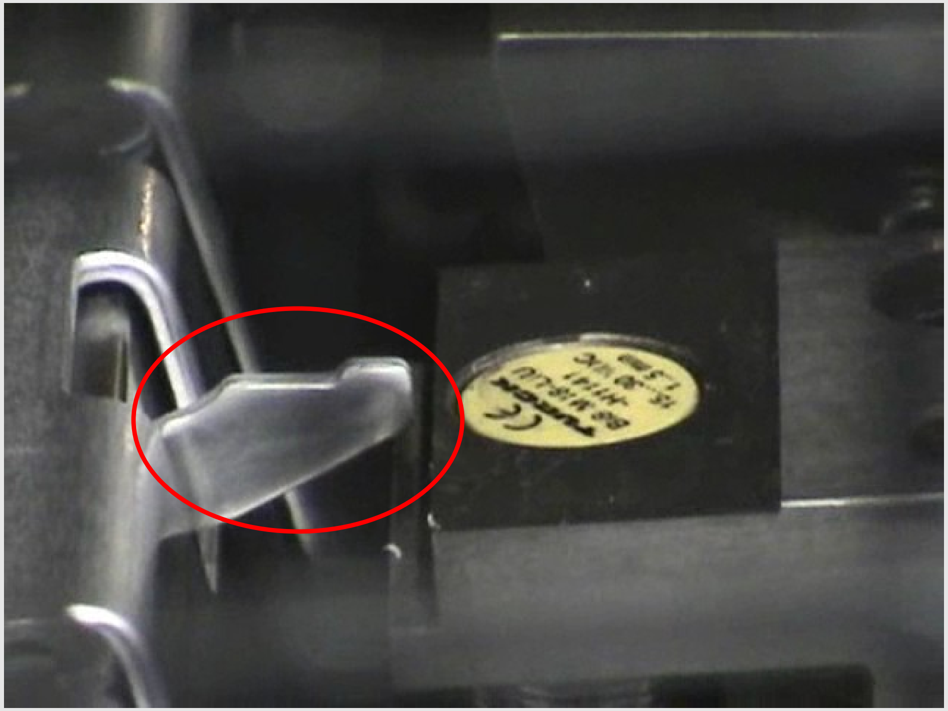


Sophisticated Applications

- Notice on the previous slide that more than one scrap station is possible. For example, perhaps the butt weld of a joined coil will not successfully feed through the bend station. We use a PLS set to activate on a “bad” part to activate whatever rejection mechanism we have arranged. A scrap sensor on that exit counts the rejected part as scrap.
- Other sensors later in the die could also mark parts as “bad” for other reasons. Those parts would then be directed to one or more other scrap bins - each with their own scrap sensor.
- All of these scrap sensors feed the same scrap counter. Our scrap count and our scrap rate remain accurate no matter where we reject the part.
- For multiple output dies making the same part, part sensors can also feed the same part counter.

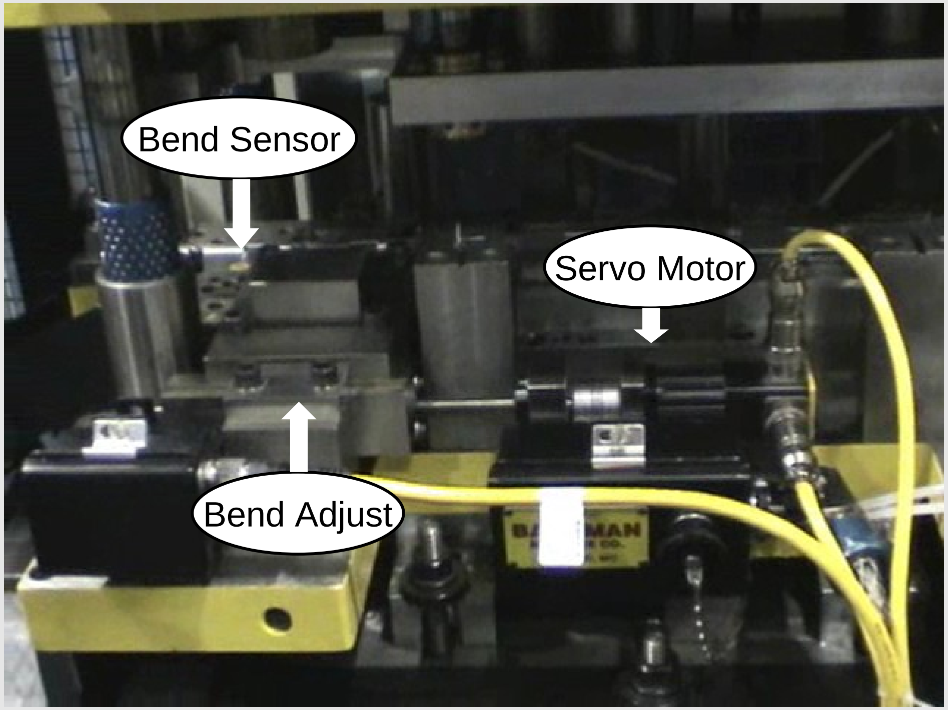
Sophisticated Applications

- Most analog proximity sensors specifications listed in their data sheet assume a certain size and material target. In the picture below, the analog sensor (yellow) is used to measure the bend angle of the tab circled in red. It does this by holding off a spring loaded steel target in the upper die. This setup allowed the sensor to detect bend angle to 0.1 degrees.



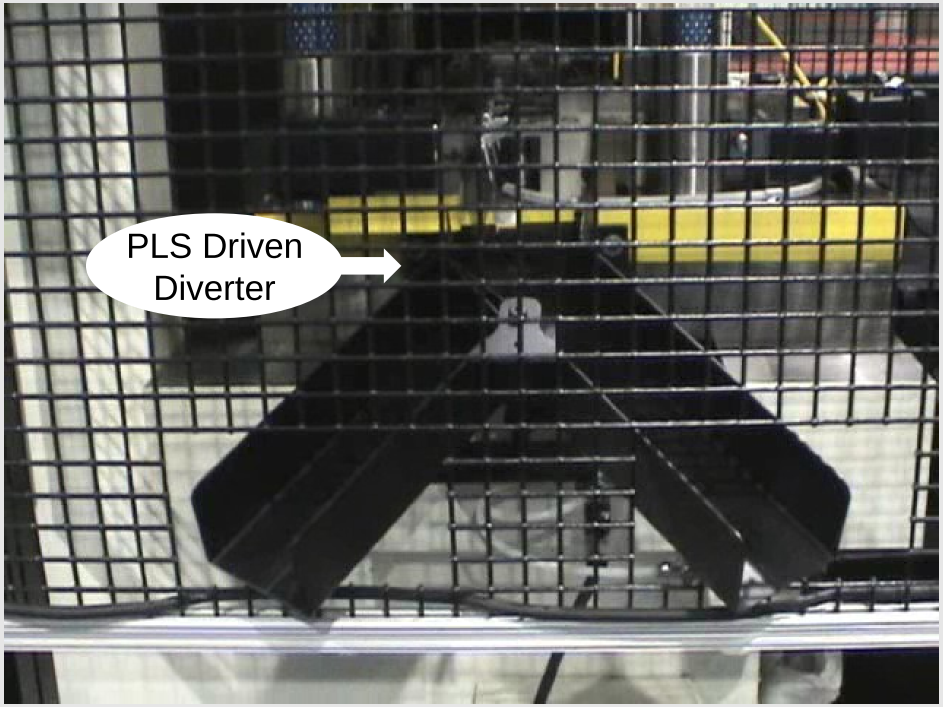
Sophisticated Applications

- Here we see the servo motor that adjusts the bend station that sets the angle of the tab from the previous slide.
- The servo is only about 3” by 3” by 7”. Sensors are not the only thing that have become smaller and more powerful.
- A worm gear drives the actual adjust mechanism.



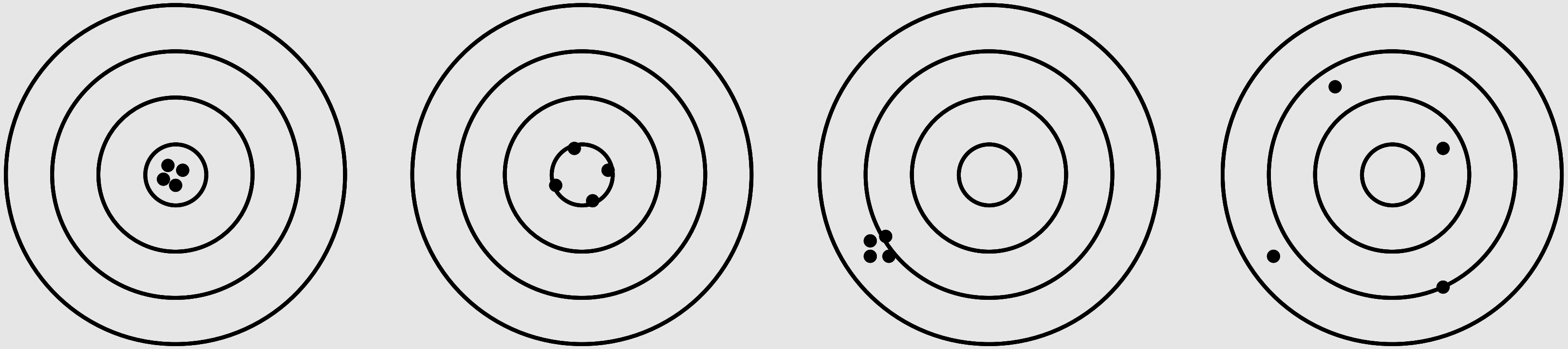
Sophisticated Applications

- This diverter was driven by a programmable limit switch set to fire on “bad” parts. It drove a small air cylinder with a spring return. “Bad” parts go one way, “good” parts go the other way.
- Note that this diverter is completely external to the die itself.



Sensor Accuracy

- How do we know what kind of accuracy we can get out of a particular sensor?
  - ***Accuracy*** - the degree of closeness of measurements of a quantity to its actual (true) value.
  - ***Repeatability*** – how close the output of a sensor matches when the target is repeatedly measured ***at the same distance*** (or whatever the sensor is measuring).



High Accuracy High Repeatability | High Accuracy Lower Repeatability | Low Accuracy High Repeatability | Low Accuracy Low Repeatability

Sensor Accuracy

- If we need accurate measurement throughout the range of the sensor (or at least at more than two points), we need accuracy.
- If we just need two points to be correct (where the part is too long or too short for instance), then we may be able to use the sensor's repeatability.
- The repeatability spec is always as good as or better than the accuracy spec.
- In sensor data sheets, the accuracy can be called "accuracy", "linearity" or "non-linearity". They all mean "how close does the sensor response come to the ideal straight line that it should be". This is usually specified in percent of full scale, but some datasheets will just list the unit. If a sensor is specified to work from 1 to 5 mm, and the linearity is 3% of full scale, then the base accuracy of the sensor is (.03 X (5mm-1mm)) = 0.12mm or about .005in.

Sensor Accuracy

- In sensor data sheets, repeatability is usually called “repeatability” or “repeat accuracy”. The very same sensor that had 3% of full scale linearity, has 0.2% repeatability. That is, when the sensor reads the same voltage it did the last time you took that measurement, you are within (.002 X (5mm-1mm)) = .008mm or .0003in of where you were.
- When trying to use the repeatability of the sensor instead of its accuracy, you MUST choose your two calibration points to be the “long” and “short” limits for the part.

Sensor Accuracy

- In addition, the data sheet will usually specify a “temperature coefficient”. The reading of the sensor will change with temperature. Unless explicitly stated differently in the datasheet, you should assume the accuracy and repeatability specs are specified assuming the temperature doesn’t change. The temperature coefficient is usually specified in “+- units per °C” or “+- % Full Scale per °C”. If your plant experiences temperature changes through the year, then this has to be factored in and added to both accuracy and repeatability specs. If this spec is 0.125% per °C and your machine sees 15°C temperature changes through the year, then you must add (.00125 X 4mm) X 15 = 0.075mm or .003in to the accuracy and repeatability of the sensor.

Sensor Accuracy

- The PLC, control, or amplifier that you use to read the sensor will also have its own accuracy, repeatability, and temperature coefficient specs. These must be added to the sensor spec to get the final, true, accuracy and repeatability specs.
- Avoid the temptation to use a “magic” sensor that happens to work better than the spec, as many will. When that sensor needs to be replaced, the new sensor may not be much better than the spec. Your process may work fine for a while, maybe even months, and then suddenly its not working and nobody knows why.
- Since non-linearity is usually a percentage of the full scale range of the sensor, choose a sensor with the smallest range that will work for your application. 3% of 10mm is 0.3mm, 3% of 1mm is 0.03mm. Smaller ranges will typically result in better accuracy.
- If you have doubts about calculating these values or the datasheet is unclear, it’s worth a call to the sensor manufacturer applications engineering department for some clear answers.

Conclusion

- Sensors have come a long way in the last several years. They are smaller, more rugged, more accurate, come in more form factors, and are easier to apply.
- Control systems have also advanced. Canned logic for some extremely sophisticated measurement and control functions have lowered the barriers for applying this technology in the pressroom. Systems are available that work to 2000 strokes per minute.
- Process visibility is the key to successfully applying and using analog sensors.
- Many of the benefits of this technology do not require die modification.
- Implementation of part measurement, die-adjustment, and part tracking can result not only in 100% verification of critical part features, but also in significantly increased machine utilization, accurate production and scrap rates, and more reliable die protection.

Questions?

Thank you!

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