TechNote

Error influences of draw-wire sensors

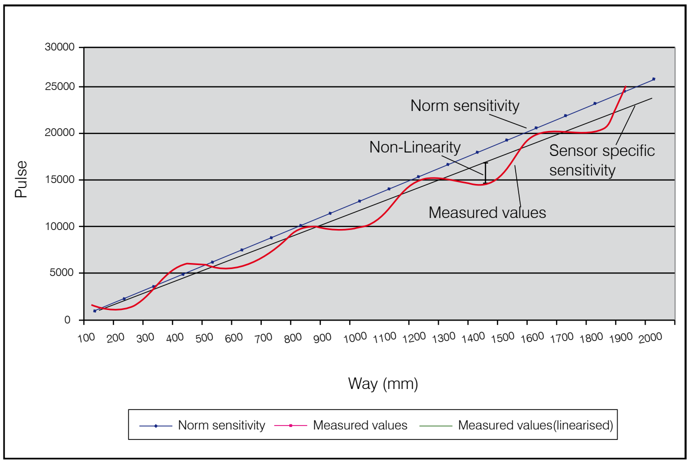
1. General

The following explanations should demonstrate in line with actual practice, which error influences are likely to occur when using commercially available draw-wire sensors and should therefore be considered carefully.
Indeed, error influences that occur by way of calculation are so small that they are often largely ignored compared to the main errors. It must also be noted that many of the fundamental measurement technology terms are not standard and can therefore be interpreted very differently.

2. Errors

2.1 Sensitivity deviation

Sensitivity refers to the relationship between displacement and signal, i.e. which signal or signal change is obtained per displacement or displacement change.
When using a rotary encoder, the standard sensitivity is produced from the number of bits (per sensor revolution) of the uncoiled wire length. When using analogue sensor elements (potentiometers), this is stated in mv/mm, mA/mm or mV/Vmm depending on the type of the signal output.



Picture 1: Sensitivity deviation

<u>Example:</u>
A) WDS-15000-P115 draw-wire sensor (315.07mm/revolution) with rotary encoder 12 bits / revolution.
This results in a sensitivity of 4096 pulses / 315.07mm = 13 pulses/mm.
(The reciprocal value is then the resolution:
315.07mm / 4096 = 0.077mm)

The uncoiled wire length / revolution is calculated from (drum diameter + wire diameter)*π. Therefore, the error tolerances of the drum and the wire affect the sensitivity of the sensor. These are approx. ±0.03% for the drum diameter and approx. ±8% for the wire diameter. Therefore, as well as the “standard sensitivity” of 13 pulses/mm, there is a sensor-specific value (black straight line in the picture) which is only valid for one sensor and is determined individually for each sensor. (cf. 3) This value is documented on the measurement report and supplied with the sensor (mechanism). If a draw-wire sensor mechanism is supplied without a rotary encoder, this value refers to the reference rotary encoder used at Micro-Epsilon. If a rotary encoder with a different pulse count is used, this value must be converted accordingly.

B) WDS-15000-P115 draw-wire sensor with hybrid potentiometer and potentiometer output signal.
Just as in Example A), there is a standard sensitivity and an actual sensitivity for the reasons stated above. This is expressed in mV/Vmm and is typically around 0.067mV/Vmm for this sensor. The resolution for analogue outputs is limited by the noise of the electronics used.

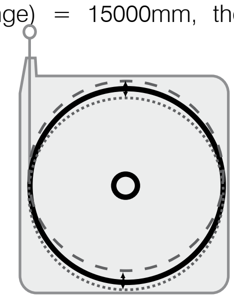
In practical use, this sensitivity deviation (= “conversion accuracy” or “slope error”) can be compensated for relatively easily, e.g. by 2-point calibration or by using the sensor-specific sensitivity. Of course, the sensor can also be used with the standard sensitivity, however, an error in the spacing of the two straight lines shown in the picture is then produced. Thereby, the absolute error increases as the draw length increases. If it is expressed as a percentage, it usually refers to the current measured value.

2.2 Linearity

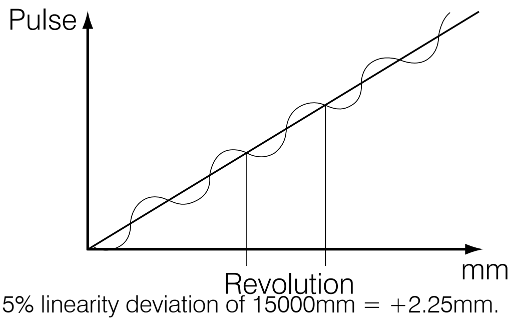
Linearity (= “non-linearity”, “linearity deviation” or independent non linearity) refers to the maximum deviation for the linear sensor behaviour. This deviation is usually related to the actual sensitivity of the sensor (as shown in the picture) and stated as a percentage of the measurement range (= f.s.o: full scale output). Standard sensitivity is referred to very rarely and if so, is designated as “absolute” (non) linearity.

2.2.1 Sensors with encoder

Example for WDS-15000-P115: linearity = ±0.015 FSO.
MB (measuring range) = 15000mm, therefore the permitted



Picture 2: Errors caused by tolerances on the shaft, drum and bearings

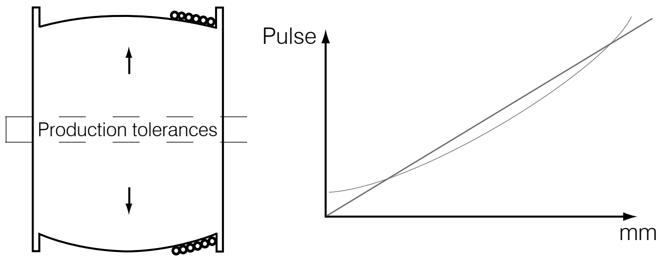


±0.015% linearity deviation of 15000mm = +2.25mm.

Picture 3: Errors for every drum revolution

The causes of these errors can be drum runouts, eccentricities of the bearings and the shaft, or changes in the wire diameter. Drum run outs and eccentricities have identical effects for each drum revolution. This sine-shaped curve is superimposed on the sensitivity curve with an oscillation range of one drum revolution. Thereby, the complete absolute error can already occur within the first revolution; it will not become larger as the wire is drawn further.
This means that sensors in the same series but with different measuring ranges, are specified very differently in relation to the linearity, as the absolute error is always the same.

Example for WDS-15000-P115: linearity ±0.015% FSO

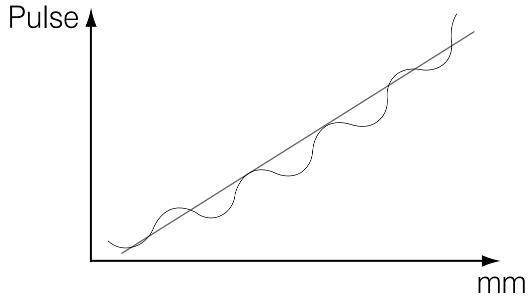


Picture 4: Errors caused by production tolerances

WDS-7500-P115: linearity ±0.03% FSO
However, this error cannot usually be compensated for, or only with a lot of difficulty.
As well as the effects, which are the same for every drum revolution, there are others that are superimposed on this curve with other oscillation ranges. For example, if the wire diameter varies, this change can cover several drum revolutions.
The effects outlined above always occur in combination, so that the isolation of a single error is not possible in practice.

2.2.2 Sensors with analogue sensor element (potentiometers)

When potentiometers are used, the complete non-linearity of the sensor is largely determined by the non-linearity of the potentiometer. This is typically between ±0.1% and 0.5% of the measuring range. Therefore, the other effects described under 2.2.1 play no



Picture 5: Both error curves superimposed

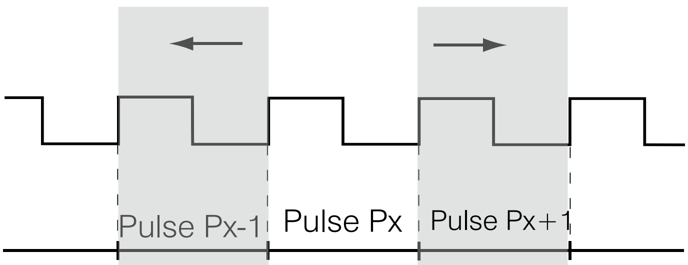
role in practical use for sensors with an analogue sensor element.

2.3 Temperature errors

Two different types of temperature error are produced when using draw-wire sensors. On the one hand, is the temperature error of the sensor element (rotary encoder or potentiometer with electronic evaluation). This error is usually specified with % FSO / °C for the electronics. On the other hand, “mechanical” errors are also produced due to the expansion of the material. The drum and the measuring wire are affected by this.
Theoretically, this could be calculated for a constant temperature. However, in practical use, temperature gradients i.e. temperature change or different temperatures at different places of the wire or sensor, are the problem. This makes a calculation practically impossible. Therefore, only the temperature error of the electronics or the sensor element is usually specified for draw-wire sensors.

2.4 Reproducibility errors

Due to the way the system operates, the reproducibility error for draw-wire sensors is very small and is almost the same as the resolution, i.e. ±1 bit for digital sensor elements and determined by the noise of the electronics for analogue outputs.
When the distance changes, the encoder jumps to the next value at defined points. If the distance is measured exactly at a pulse



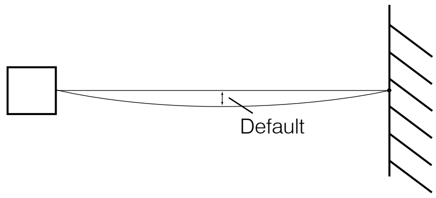
change, the value can be -1 pulse in one case and +1 pulse in the other.

Picture 6: Reproducibility error example

2.5 Wire sag

A measurement error is produced for a horizontal installation of the draw-wire sensor due to the wire sagging. The amount of sag depends on the drawn out wire length, the specific gravity of the wire and the spring forces of the sensor.

In the case of a WDS-40000-P200 for example, the wire can sag by up to 160mm when completely extended. Nevertheless, the error resulting from this is rather small in comparison, for example, with the linearity deviation (0.002% as compared with 0.01%) and



so can usually be ignored. However, the necessary space for this must be provided for the installation.

Picture 7: Example of wire sag

3. Measuring technique for determining linearity

Every draw-wire sensor or mechanism is measured on a calibration system before delivery. In doing so, the sensitivity, linearity and wire forces of the sensor are measured and documented. A glass scale is used as a reference system for measuring ranges up to 6m and a special take-up device with rotary encoder is used for larger measuring ranges. The sensor is drawn out completely and retracted again; a discrete number of points are measured in doing so. Based on these measurement results and the values of the reference system, a straight line regression is calculated according to the smallest quadrant method. The slope of the straight line regression therefore corresponds to the actual sensitivity of the sensor. The maximum deviation of the measured values from the straight lines is the specific linearity of the sensor, whereby only an OK / NOT OK assessment, i.e. within or outside the specification, is performed.

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