The incremental encoder – further evaluation possibilities of incremental encoder signals (part 2)

White Paper

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Incremental encoders are used in virtually all areas of industry when it comes to the measurement of displacement , angles, velocities, RPM, etc. The measurement of derived quantities comes from the measurement of time. In the previous White Paper (part 1), the basic operation principals & fundamental signal evaluation possibilities were covered when it comes to single-track incremental encoders. As already mentioned, it is often not only necessary to know the rate at which something moves, but also the direction in which it moves. For this reason, many have a second incremental track (quadrature) whose function is described in more detail below. Usually, the incremental signals are utilized in digital form, which can also be transformed by methods such as pulse multiplication, but deliver only a limited increase in resolution.If an additional resolution is required, there are incremental encoders that generate two 90° offset sinusoidal signals. With these so called SinCos encoders, as will be described in detail below, much higher resolutions can be achieved. Also, further opportunities for increased accuracy are dealt with when measuring velocity. Finally, providing a comfortable encoder interface, different ways of measuring time are explained.

Recognizing the direction of motion:

For direction recognition, as previously mentioned before, a Quadrature (two-track) incremental encoder with two digital signals with a duty cycle of 1:1 is generated. The duty cycle is the time sequence of the state of logic 1 (high) and logic 0 (low). Since the edge change of the digital signals from low to high in the second track (Y-track) of this incremental encoder is dependent upon whether it is carried out either a quarter division before or quarter division after the edge change at the first track (X-track), the direction of movement can thus be known.

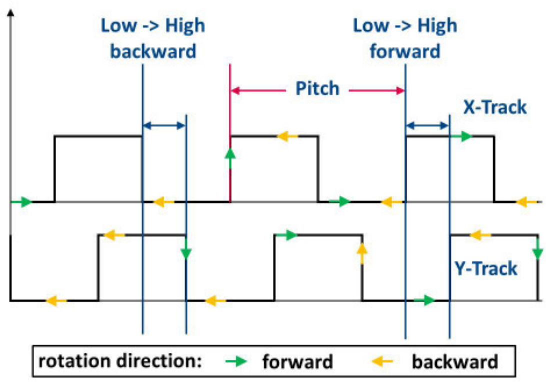


Figure 1: *Rotation recognition by the use of a Quadrature (two-track) incremental encoder.*

Increased resolution through pulse multiplication:

At the edge change, both tracks are often used for pulse multiplication in order to increase the resolution even further. Based on the above duty cycle, the digital signal produces a pulse on both tracks from each edge change (High -> Low, Low -> High).The resulting pulse scheme has led to an increase of the number of evaluable pulses by a factor of 4. This also results in an increase in resolution by a factor of 4.

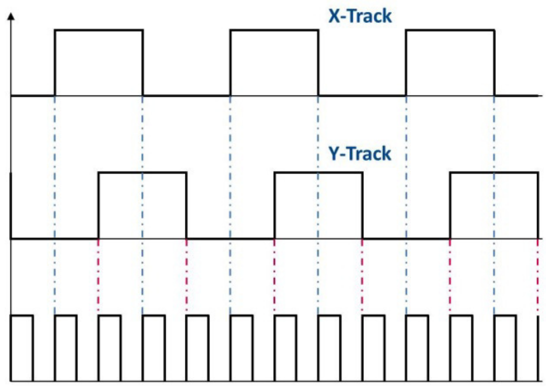


Figure 2: *Pulse multiplication by converting all edge changes.*

This type of resolution enhancement can quickly lead to errors when the duty cycle ratio is not exactly 1: 1, or when the offset of the two tracks of the uniform (quarterly) pitch is different. If either of these problems, or even both occur together, a pulse pattern is generated which may result in large errors of the velocity measurement. Because of an unbalanced pulse scheme, shorter and longer pulse intervals will occur within a given period. This is especially important when it comes to velocity measurements. Since the velocity is determined from the measured time between two successive pulses, this will lead to ever changing results. Example:

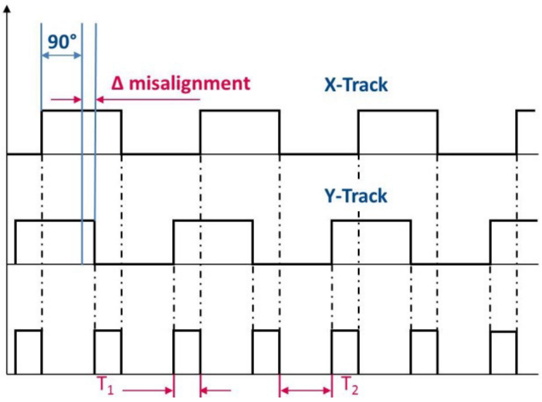


Figure 3: *Unsymmetrical pulse scheme due to misaligned edges.*

Resolution improvement through analysis of intermediate analog values:

An improvement in resolution by the analysis of intermediate analog values gives much better results and capabilities than the pulse multiplication by evaluating all edges. For this type of resolution enhancement, incremental encoders are used that output the two 90° offset sinusoidal signals. Each period of a sine wave is caused by the continuously changing influence of the increment marker on the signal output of the sensor during the movement. These are referred to as SinCos encoders. For the explanation, we assume that a rotary incremental encoder whose angular increments consist of uniform subdivisions of a circular disk. By scanning the tracks on the exact angular position, each sample point of the rotating object to be measured is obtained. In an orthogonal system with the circular functions sine and cosine, as is created by SinCos encoder, each point of this circle can be represented. The sine/cosine-shaped signals divide the respective angular increments in 4 quadrants (90°). By simultaneously detecting the signals, their respective quadrants can be uniquely determined.

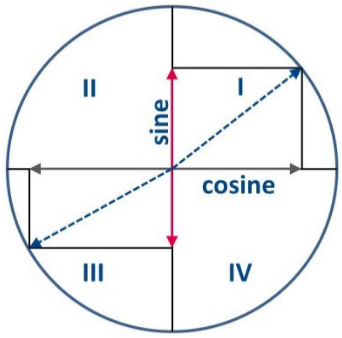


Figure 4: *Orthogonal system for determining the position within the circle.*

For high resolutions, linear signal sections preferably need to be evaluated. For this reason, the two voltage signals of the SinCos encoder are sampled from the marked sections in the image for the resolution enhancement, because here, the sinusoidal signal allows an accurate classification of the displacement at high resolution.

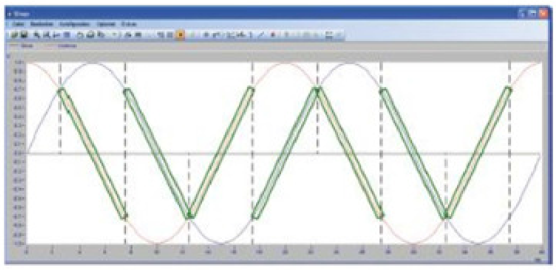


Figure 5: *Signal sections are used for the analysis of intermediate analog values.*

At each time point, both signals are sampled. From the information about the current quadrant alone, the resolution of the position determination is already four times that of counting a pulse in a single-track incremental encoder. By this comparison of the two values of the sine wave with an amplitude of the cosine tangent, dedicated independence is achieved. This is necessary to be able also use incremental encoders with unknown amplitude in high resolution, since this may change as a result of wear and tear. In addition, there are many SinCos encoders whose waveform is frequency dependent. By increasing frequency to its bandwidth limitation of the signal in opto-electronic SinCos encoders, and by decreasing its harmonic component, its shape changes from triangular toward sinusoid. Another problem resides in the asymmetry of the sensor signal due to manufacturing tolerances between the different sensor manufactures. In case of signs of wear or manufacturing tolerances of SinCos encoders, calibration of the sensor is recommended. The well-known stopping behavior of a wave with high inertia could be used to record the exact waveform over the angle and to save it. Early on, SinCos encoders had been used to increase the resolution, however, for the purposes of evaluating the pulse multiplication and not the intermediate analog values. For this type of evaluation, the weights of the two signals are compared. Through suitable weighting, pulses at every angle (u) can be created by an ideal process. In addition, the comparison position is independent of the signal amplitude.

$$\sin(\varphi+\theta) = \sin(\varphi)\cos(\theta) - \cos(\varphi)\sin(\theta)$$

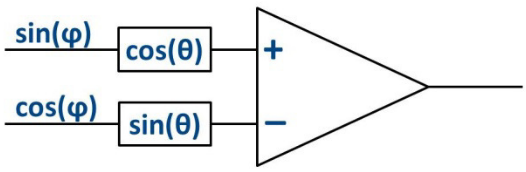
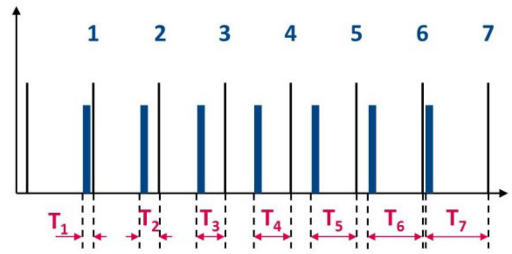


Figure 6: *Comparator circuit for weighting the output signals of a SinCos encoder*

The evaluation of the intermediate analog values, in reality, would always bring a lower resolution increase with a theoretically high sampling frequency possible. The main reason for this is that the signal generated by SinCos encoders in its form never exactly corresponds to a sine. As a result, an increase in resolution by a factor of 256 and an increase in accuracy are achieved by a factor of 10. A big advantage in the use of SinCos encoders and analysis of intermediate analog values is the static resolution enhancement; there are also intermediate values at a standstill. This information is advantageous especially for control applications, because control modules thereby obtain a precise set actual value and thus a radical swing is avoided, which leads to increased wear.

For displacement measurement of objects such as large drive shafts with sufficient inertia, there is the possibility of dynamic displacement measurement for increased accuracy. In the dynamic position measurement, the speed of rotation is determined from the preceding sample intervals. It can be performed for an extrapolation of different orders, depending on the available computing power. With a first-order extrapolation from the past two determined velocities, the path that has been covered in this period can be determined for the next sampling interval from the measured time between pulse and sampling. With this information, objects with sufficient inertia can achieve an enormous increase in resolution.

For example:



From the first two sampling intervals, the extrapolated velocity can be determined (in example T_4) from the measured time and the distance travelled. This additional path that the measurement object has traveled between the time of the pulse and the sampling timing is on the path that is derived from the number of pulses is added in this sampling interval. Without this process, the measurement error would continue to rise in pure pulse counting until sampling time point seven because of an increase in the time difference between the arrival of the position information (pulse) and the output (sampling). In this type of measurement, it must be taken into account that when speed decreases, the number of evaluable pulses per sampling interval decreases and thus, the accuracy of the measurement. The determination of the velocity and from the time between the pulse and sampling time point path to the dedicated displacement is also used for incremental encoders, which characterize the zero pulse instead of a separate zero pulse track by omitting an increment. This lacking increment then forms the zero pulse. The result, due to the lack of short-term pulse rate change, is detected by the encoder interface as the zero pulse and processed accordingly. It is important to ensure that the number of incoming pulses within a sampling interval is as large as possible, so that the displayed velocity change remains as small as possible by the lack of the increment.

Comfortable encoder interfaces usually offer additional options for measuring various signal timings. It can be high times, low times or measure the ratio of the two to each other.

This property of encoder interfaces is primarily used for the pulse-width measurement to determine the pulse-width modulated signal to the corresponding desired value. In the example shown here, the output value is simplified by the length of the pulse. Pulse width modulated signals for driving machines under operation and a pulse width modulation is particularly interesting.

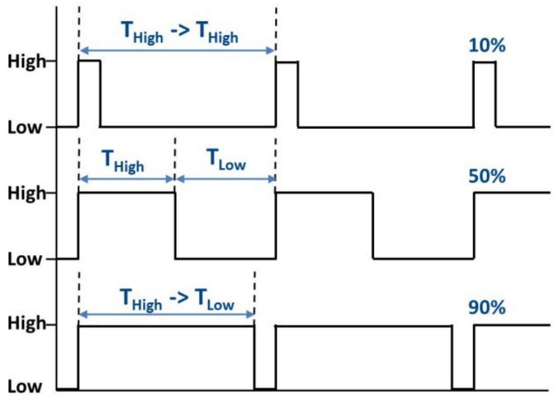


Figure 7: *Measurement of various pulse times.*

The evaluation possibilities of incremental encoder signals described here extend the field of application of incremental encoders significantly. However, these possibilities are not fully known and to accomplish their realization, it takes the appropriate technical know-how, which is not the case everywhere. In general, only one of these options described here are available from an encoder interface and implemented satisfactorily. An encoder interface that provides all the additional evaluation options described here is the exception. This exception can be found, as expected, at the firm imc Meßsysteme GmbH in the form of HRENC-4 (high resolution encoder interface).

Figure 8: imc CRONOS*flex* HRENC-4 module

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