TIMKEN
Where You Turn

Application Note: MSS-7302

Using the MPS160 ASIC

Reference Documents:

MPS160 Series data sheet

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1.0 Overview

Timken's MPS160 encoder ASIC is engineered to produce the same high resolution digital signals as a traditional optical encoder. In normal operation, the MPS160 ASIC produces digital quadrature signals (square wave) that contain position and direction information. The MPS160 can also produce multiple index signals. The primary difference between the MPS160 and an optical encoder is the sensing technology used. The MPS160 ASIC is based on magnetic technology. The MPS160 ASIC contains a series of Hall sensor elements with on chip processing to produce digital quadrature and index signals.

The magnetic technology and on chip processing employed offers a number of operational benefits including larger air gaps, rugged environment operational reliability and high shock and vibration resistance.

The MPS160 ASIC is designed to produce a programmed resolution that is up to 40 times the base resolution of the magnetic target wheel being sensed. This high resolution is accomplished through on board processing of the Hall sensor elements into two channel quadrature output. With 4 edges per pulse high resolutions are achievable with small diameter targets. The accuracy of the output signal is a non accumulating one pulse per revolution for absolute position and a non accumulating one edge per revolution for incremental position.

The MPS160 ASIC output signals can be used in position and speed control applications.

2.0 Quadrature Signals:

The MPS160 ASIC is used in "Incremental" Encoder applications and operates down to "Zero Speed". Approximately 80% of all (Optical) encoders are configured as "Incremental" Encoders. Incremental encoders are characterized by the signals they produce. The output from an incremental encoder consists of two signals with a quadrature format. The quadrature format consists of two square wave signals, each with a 50% duty cycle with a nominal 90 degree phase relationship between the two quadrature square waves. The most common identification of the two waveforms is signal A and signal B.

The quadrature relationship of the two waveforms allows the direction of rotation to be detected when either signal A or signal B changes state. Rotating clockwise the B quadrature signal will change from the “0” state to the “1” state before A quadrature signal changes. See the chart below:

Signal A	Signal B	Quadrature State (4 states total)
0	0	A
1	0	B
1	1	C
0	1	D
0	0	A
1	0	B
1	1	C
0	1	D
0	0	A

Note: Moving down the chart from state A to B, or B to C, ……. represents (CCW) Counter Clockwise movement. Moving up the chart represents (CW) or Clockwise movement.

3.0 Resolution:

Typically, the resolution on an incremental encoder is in Pulses Per Revolution (PPR). This is equivalent to Cycles Per Channel, or the Line Count of the encoder. The encoder produces two signals and each signal rises once and falls once per Pulse generating a total of 4 edges per pulse, two from each signal (channel). These edges are used to calculate position or speed for each (PPR) Pulse. There is four times the number of edges than the (PPR) rating of any quadrature encoder. {IE: A 1000 (PPR) encoder produces 4000 edges of positional information in one revolution}

The MPS160 ASIC uses an array of on chip sensing elements along with on chip patented signal processing to produce quadrature signals that are up to 40 times the resolution of the target magnet being sensed. The ability to produce a (PPR) signal with a higher resolution than the target magnet pole pair count allows the MPS160 to operate with larger magnetic pole pairs. The larger pole pairs and associate air gap make application of the technology well within real world sensor to target tolerances.

> Example - A MPS160 ASIC sensor in 32X mode sensing a 64 pole pair magnet:
> The PPR rating on this system is 32 * 64 = 2048 PPR. From the first paragraph in this section we realize that this encoder will actually produce 4 edges that can be used to calculate position or speed for each (PPR) pulse for a total of 8192 edges that can be used to calculate position or speed for each revolution of the target magnet.

4.0 Accuracy:

After resolution, accuracy is the most important characteristic of an incremental encoder. Accuracy can be expressed independently or as a function of an encoder's resolution. In general the accuracy of an encoder signal can be compared with an absolute reference angle or as a variation from one pulse length to all the other pulse lengths produced in one complete revolution.

For example, a 512 PPR (2048 edge) encoder has a 360º / 512 = 0.703º per cycle or 0.1757º per edge. The typical tolerance on the true position of any of the 2048 edges produced by our 512 PPR encoder is useful if we would like to use the encoder to position a shaft to a specific location. A typical "Absolute position error" of the MPS160 ASIC encoder signal is half again as fine as the encoder's resolution, in this case one part out of 1024 or +/- 0.3515º. The "Incremental position error" of the encoder is the ideal angle between like edges on channel A or B as compared with the actual angle of like edges on channel A or B. This is much smaller than the "Absolute position error" at 25% of the "Absolute position error". In our example the typical "Incremental position error" would be better than +/- 0.0879º.

5.0 Positioning and Speed Applications

5.1 Positioning Applications

Quadrature encoders are ideal for positioning applications. To take full advantage of the encoder's resolution, the A and B quadrature signals should both be used with a full quadrature decoding counter. Either a hardware or software full quadrature decoding counter ensures any reversal of direction or dithering of the rotating part will not introduce an error in the calculated position of the shaft. The accuracy of the position for the start to finish will be based on the encoders "Absolute position error" at the start of the maneuver plus the encoders "Absolute position error" at he end of the maneuver. Or in the case of the 512 PPR encoder example above the error would be no more than 2 * 0.3515º or 0.7030º.

5.2 Speed Applications

For speed control applications: Quadrature encoders work well for speed control applications. As with positioning applications, the A and B quadrature signals should both be used with a full quadrature decoding counter to take full advantage of the encoder's resolution. Either a hardware or software full quadrature decoding counter will ensure that any reversal of direction or dithering of the rotating part will not introduce an error in the calculated speed of the shaft.

Special consideration is required when using an encoder in speed control applications where resolution is confused with accuracy. In many applications the time between consecutive sensor signal edges is used to calculate an instantaneous speed. This is a reasonable technique to use with very low resolution encoders or pulse wheels of 1 to 60 PPR. Using this technique with higher resolution encoders (100's or 1,000's of PPR) the small "Absolute position error" and /or "Incremental position error" becomes a significant percentage of the angle between edges. Measuring the time between two consecutive edges or two consecutive pulses to calculate speed is not recommended with using high resolution encoders. Alternative methods that count pulses for a fixed length of time or measuring the time between a series of edges or cycles will result in a much more accurate calculation of shaft speed.

Example - A 1024 PPR encoder is used to measure a shaft spinning at a true 500 RPM:

> Encoder Specification:
> Resolution: 1024 PPR 360º / 1024 = 0.3515º per cycle or 0.0879º per edge
> Absolute position error: +/- 0.3515º.
> Incremental position error: +/- 0.0879º.
>
> Speed calculated by measuring time between rising edges on one channel:
>
> Ideal calculations:
>
> > 500RPM / 60 Sec. = 8.333 RPS
> > Timing starts at 0º and stop timing at 0.3515º produces
> > a time interval of 1 / (1024 * 8.333) = 117 uS
> > 117 uS * 1024 = .12 sec / Rev. = 8.33 RPS = 500 RPM
>
> Real Calculations: (Taking into account Incremental position error: +/- 0.0879º)
>
> > Timing started at 0º - 0.0879º and stopped at 0.3515º + 0.0879º
> > The total angle between the two edges is 0.3515º + 2 * 0.0879º = 0.5273º not 0.3515º. The time interval at a constant 500 RPM is 176 uS.
> > Calculating speed based on a 176 uS time span would be 176 uS * 1024 = .18 sec / Rev = 5.54 RPS or 333 RPM Calculated (An error of 167 RPM or 33% error!)

Speed calculated by measuring the time between one rising edges and an edge twenty cycles away on one channel:

> Ideal calculations:
>
> > 500RPM / 60 Sec. = 8.333 RPS
> > Timing started at 0º and timing at stopped 3.515º we would
> > have a time interval of 20 / (1024 * 8.333) = 2340 uS
> > 2340 uS / 20 * 1024 = .12 sec / Rev. = 8.33 RPS = 500 RPM

Real Calculations: (Taking into account absolute position error: +/- 0.3515º)

Timing started at 0º - 0.3515º and timing stopped at 7.030º + 0.3515º.
The total angle between the two edges is no longer 7.030º but is
20 * .3515º + 2 * 0.3515º. = 7.733º The time interval at a true 500 RPM
would be 2578 uS 2578uS / 20 * 1024 = .132 sec / Rev =7.57 or
RPS = 545 RPM Calculated (An error of 55 RPM or 11% error)
{Note: Sampling 200 instead of 20 pulses would reduce the worst error to about 1%}Speed calculated by counting edges for a fixed time period:

Ideal calculations:

500RPM / 60 Sec. = 8.3333 RPS
Timing started at 0 time and timing stopped at 0.1 seconds. During the 100 mS time interval the shaft turns 300º or 300/360 * 4096 edges / revolution = 4313.33 edges at 0.0879º per edge. Taking into account absolute position error: +/- 0.3515º which is approximately +/- 4 edges.
the speed would be 4313 edges +/- 4 edges

Ideal edge to edge = 1 / (4096 * 8.333) = 29.296 uS / edge

3413 edges in 100mS = 29.299 uS / edge = 500.05 RPM
3417 edges in 100mS = 29.265 uS / edge = 499.47 RPM
3409 edges in 100mS = 29.334 uS / edge = 500.65 RPM

It is clear that counting a large number of edges can produce a much more accurate speed reading than can be calculated by measuring the time interval between adjacent edges or from one cycle to the next cycle.

Other considerations for speed calculations:

- Accuracy can be improved by measuring time between pulses in multiples of 40 cycles. This technique eliminates many repetitive sources of error in the magnetic target and in the MPS160 circuitry
- To avoid error in readings due to off center target wheel mounting the user should avoid taking speed readings that sample pulses at ½ rotation intervals. ¼ rotation intervals will produce less average error.
- Sampling over a full 360º rotation will eliminate the most systematic errors and produce the most accurate speed readings.
- A weighted or non weighted sliding window average speed calculation will produce the most accurate speed reading.