OMNICODER ® Programmable Optical Encoder

White Paper
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I. Origin of a Programmable Encoder

The basic concept of the Omnicoder came about when a customer needed help solving a registration problem. For their purposes they needed to mark a plastic ribbon with a small registration mark every 0.500 inch. What made this issue problematic was the unusual combination of requirements inherent in their mechanism. First, it was necessary that the accuracy of the marks stay within +/- 0.010 inch from their true position over an 8 hour period with the ribbon moving at 10 feet per minute. In other words, after the end of an 8 hour shift a total of 57,600 feet of ribbon would be processed, 115,200 marks would have been placed and all marks would be within +/- 0.010 inch from their true positions. Absent any better technological solution, the customer’s chose to monitor the registration mark and periodically reset the machine to bring it back into registration.

To complicate matters, the ribbon needed to pass over an 8.000 inch diameter roller attached to a 1000 count per revolution optical encoder mounted to the roller's axis. Using the encoder's quadrature signal produced a quadrature edge every 0.00628318530 inch on the circumference of the roller [(8” x π) / (1000 x 4)]. If we divide this value into our 0.500 mark distance, then mathematically it is necessary to produce approximately 79.5775 encoder counts between each mark.

So herein lies the challenge: how does one produce a non-integer encoder count value? The solution is that sometimes the encoder counts out 79 edges and sometimes it counts out 80 edges, so that in the long term the average count is 79.5775...

A quick look at TABLE 1 on the following page shows an example of an encoder count sequence which results in an average count value of 79.6 over the first 10 marks.
TABLE 1 – ACCUMULATED ERROR FOR 79.6 CPT ENCODER OUTPUT

If we graph the accumulated position error for the first 100 mark positions it is easy to see the non-periodic count values and also demonstrate that the positioning error stays within the allowable +/- 0.010 inch specification (see GRAPH 1). Note that the average encoder count over these 100 cycles is now 79.58 – a little closer to the 79.5775 required.

This simple exercised validated that the concept is mathematically feasible and the next step was an algorithm to generate the optimum sequence of the 79 or 80 encoder counts based on the position relative to the starting point. There are many possible ways to accomplish this conceptually, however within the Omnicoder this solution was embodied with a series of interlocked electronic ring counters that produce the desired count sequence. With a sufficient number of interlocked ring counters, the sequence will not “roll over” and produce a count error in $1 \times 10^{13}$ rotations. At the rotation speed of this application it would take well over 7 million years of continuous operation before that would be of concern.
Once the concept was proven and the ring counter approach validated, a U.S. Patent No. 6,789,042 was issued on September 7, 2004 to cover the intellectual property that underlies both the Omnicoder fundamentals and the algorithm to produce non-integer encoder count values. Two additional patents (7,349,821 and 7,336,756) were issued in 2008 to cover the Omnicoder's reprogrammable feature so the ring counter values can be easily changed in the field by the customer through a software interface (ref: APPENDIX - PROGRAMMING THE OMNICODER)
II. Basics of the Omnicoder

The Omnicoder, as embodied in BEI Sensors’ Model H25 shafted encoder uses a 57,600 cycle per turn (CPT) encoder that has an internal reprogrammable module that divides the base CPT to output an integer value between 1 and 10,000 CPT. Theoretically the Omnicoder could be programmed to any value up to and including 57,600. However it is purposely limited in software for two reasons. First, very few mechanical systems are precise and stable enough to make use of more than 10,000 cycles per turn; secondly at a resolution of 10,000 cpt, the placement of the edges starts to move closer to the overall quadrature specification, so special care needs to be taken in setting up and operating the encoder. It was BEI’s desire to limit the resolution to help potential users from operating in an area that could create some issues for their control system. Keep in mind that with dual channels in quadrature, the number of quadrature counts on this encoder is $4 \times 57,600 = 230,400$ or about 6 arc seconds of resolution. Certainly, a sophisticated user under the right conditions could use a higher resolution and it is possible to specify versions of the Omnicoder that accept a higher resolution than 10,000 cpt for those instances.

Here is another example to illustrate the versatility of the Omnicoder approach. Imagine an application requiring an encoder output of 123 CPT it is necessary to divide the 57,600 base CPT by $57,600/123 = 468.29268$. This is similar to the previous example, however in this case the desired output is an integer value rather than a fractional value. By dividing the base count by 468 approximately 2/3 of the time and 469 counts approximately 1/3 of the time the system will “see” an average output of 123 CPT.

A. Source and magnitude of Output Position Error

Programmability has its trade-offs. In the general case there will not be an integral value divisor for an Omnicoder output, the transition point location of a quadrature edge on the base quadrature count (230,400) would not line up exactly with the desired quadrature edge on the output count of the Omnicoder. This is not an issue that is unique to the Omnicoder. It is the nature of any programmable encoder that relies on a high resolution base count in order to generate a lower resolution output value.
The Omnicoder circuit only sees the base CPT edges and then calculates based on the interlocking ring counter algorithm which of these edges would be closest to the desired output edge. It then outputs a phase transition (HI to LO or LO to HI) to most closely match the desired output. (see FIGURE 1) As can be seen, the actual output edges are aligned to the base CPT edges. Another way to look at it is to realize that the desired output is not always evenly divided into the base CPT, which results in the actual output edges being in a slightly different position relative to the desired output edges. This misalignment creates a small position error. It is worth noting that this small error is not cumulative over time as illustrated in GRAPH 1 in section 1 of this paper.

The maximum variation of the actual output position of a quadrature pulse from the desired position of that output pulse would be one count of the base resolution in quadrature or just under 6 arcsecond. This position variation is about the same order of size as the mechanical noise generated by a good set of ball bearings and well below the mechanical noise of most control systems. Gear sets, as an example will measure “lost motion” or backlash in units of arcminutes which is 10 – 20 times the size of the Omnicoder position error. In other words it is not a significant contributor to the overall system position error for most systems. For typical speed control applications this small amount of variation would not be noticeable.

**FIGURE 1 – SOURCE OF POSITION ERROR**

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B. Producing the Index Signal

One other aspect of a programmable type encoder that is worth mentioning has to do with the generation of an index pulse. For most applications, where speed control is the objective, then the index is generally not used. In instances where the index is used to establish a home or “zero” position for set-up, then there are some subtleties to the index on a programmable encoder. There are two different conventions to the gating and length of the index pulse that are widely used and will be discussed briefly later on. (In point of fact there are many different ways to represent an index, however we will cover only those which are in most common use.)

On initial power-up, like all incremental output type of encoders, the Omnicoder circuit does not know its position relative to the physical reference such as the encoder index mark internally on the code disk. After power-up, as the encoder's shaft is rotated, the Omnicoder will start producing a quadrature signal output immediately which is based on its programmed resolution, regardless of the relative orientation. When the encoder's normal internal index signal (based on the internal high base resolution) is detected, the Omnicoder circuit must produce an index signal properly synchronized and scaled to the programmed CPT at the next available opportunity.

This initial index mark cannot be produced until after the internal electronics have detected the index position encoded on the Omnicoder’s code wheel. As a consequence, the initial generation of the index pulse relative to the output signal line will be dependent on the rotational direction of the encoder shaft after power-up.

Described another way; after power-up, if the encoder shaft is rotated clockwise until the internal index signal is detected, the Omnicoder circuit will produce a synchronized index signal clockwise of the internal index. Conversely if the encoder shaft is rotated counter-clockwise until the internal index signal is detected, the Omnicoder circuit will produce a synchronized index signal counter-clock of the internal index (see FIGURE 3). Regardless of when the index is first generated, the Omnicoder circuitry will faithfully reproduce the index in the same location for all subsequent revolutions regardless of any further change of direction.
As a practical matter, when using an index to set up a piece of equipment or to locate a “home” position, good operating practice is to always approach the reference point from the same direction. This is largely due to issues of mechanical backlash more than anything else. Consequently, this subtlety of index positioning based on initial direction of rotation rarely comes into play, but it is worth knowing about.

In the illustration of FIGURE 2, the index has been represented as being aligned (gated) with the negative going portion of the B Channel. This is one of the standard index conventions and allows for a high degree of precision, since there will always be an A channel transition during the index pulse and that A transition can be used to locate a reference mark on the equipment. The other convention is to place the index at a location where both the A and B channels are high. In that case the index is one quadrature cycle wide and it is only possible to set a reference mark on the equipment within the span of one quadrature cycle. For higher resolutions that is not usually a problem, but it could be for lower resolution outputs where the variation in position of a single quadrature signal could be significant.

![FIGURE 2 – PRODUCING AN INDEX](image)

The A and B channel signals are identical in the CW and CCW outputs: Only the position of the Index has moved relative to the internal index depending on whether the shaft is initially rotated CW or CCW after power-up. Once the index position has been establish, it will be faithfully reproduced at the same position regardless of any subsequent changes to rotational direction.
III. Examples of how the Omnicoder solves real world problems

- **Adjusting feed rates in a batching plant**

Imagine that there are three conveyers feeding raw material into a hopper. All the conveyers have their feed rates controlled by a variable speed motor controller using encoder feedback. The feed rate of the first (master) conveyer is set by a command from a control panel. The other two (slave) conveyer's feed rates are set up to follow the encoder signal from the first conveyer belt (encoder follower). If you increase the feed rate of the first conveyer, then all three conveyers will be increased at the same rate.

However, what if there is a need to change the feed rate ratio of the slave conveyers to the master conveyer? This can be easily done if an Omnicoder is installed as the encoder feedback for each slave motor controller. By changing the CPT of a slave conveyer's Omnicoder, a new feed rate can be adjusted independently without affecting the other slave conveyer's feed rate.

- **Programming the CPT to read engineering units on a frequency meter**

In this example, an Omnicoder is attached to a feed screw delivering material at a rate of 500 pounds per hour. The feed screw delivers 0.27 pounds of material per rotation. The frequency meter displays cycles per second (Hz). We can calculate the exact CPT the Omnicoder should be programmed to in order to accomplish this result.

\[
(500 \text{ # per hr} / 0.27 \text{ # per rev}) / 3600 \text{ sec/hr} = 0.5144 \text{ rev/sec}
\]

The encoder needs to output 500 Hz while turning at 0.5144 rev/sec to display pounds per hour.

This now becomes 
\[
\frac{500 \text{ cycle/sec}}{0.5144 \text{ rev/sec}} = 972 \text{ CPT}
\]

which can easily be programmed as the base rate for the Omnicoder. Changing the flow rate in #/hr is simply a matter of reprogramming the encoder.
• **Changing the flying knife cut-off point from a print mark detector**

In this application, a cardboard box trimming machine is designed to cut off cardboard stock at a marker printed on the outside of the box. The manufacturer employed an optical sensor to detect this printed marker and trigger the cut-off shear. The problem is that there is other printing on the cardboard that confuses the optical sensor. To overcome this, the manufacturer used an encoder attached to a follower wheel to measure the distance between printed marks and to enable the optical sensor at the correct position. There is also a need to quickly accommodate different box sizes with different distances between printed marks. The solution is to use an Omnicoder in place of the stock “follower wheel” encoder. Now, by reprogramming the Omnicoder's CPT, these change-ups to different length boxes can be quickly and easily accomplished.

• **Electronic Line Shaft Synchronization in the printing industry**

An industrial printer wants to incorporate ten-bin automatic collator finishing equipment onto a continuous printing press. The difficulty is that the continuous press control output is 3000 quadrature counts per cut sheet length and the automatic collator needs 220 quadrature counts to advance the bin position. This necessitates a non-integer divide-by ratio of 13.636363 (3000 ÷ 220). The solution is to piggyback two Omnicoder encoders on the continuous press control and feed one into the automatic collator's input. Each can be programmed independently to the desired resolution. In addition, changes to the printer's cut sheet length would dictate a different quadrature output count from the printer. This could be easily accommodated by reprogramming the Omnicoder modules to maintain the correct ratio.

**IV. Best uses for a programmable encoder**

As can be seen by the above examples, the Omnicoder programmable encoder offers many advantages to industrial design challenges by having the flexibility to specify the CPT at any time during the design and prototyping phase. It also allows for “on-the-fly” adjustments to machines that may require a variety of different set-ups to run different material.
In summary, here are the benefits to specifying the use of the Omnicoder product:

- Simple to program (see APPENDIX – PROGRAMMING THE OMNICODER)
- Installs just like a standard encoder – no special tools required
- Instant positive indication on the programmed value via software
- High speed operation due to the high base count
- Wide range of possible CPT (1 – 10,000 cpt standard)
- Automatic index pulse positioning
- Easily change CPT for prototyping situations or machine set-ups
- Reduce stock of different CPT encoders for maintenance (keep only one in stock and program it as needed)
APPENDIX – PROGRAMMING THE OMNICODER

Once the USB driver and program software are installed on your PC, programming the Omnicoder to any value between 1 and 10,000 CPT is done in three easy steps.

INSTALLING THE DRIVER AND SOFTWARE

Step 1 – Install Drivers
- Go to www.beisensors.com/downloads to view the download page
- Click on the “Windows: USB Virtual COM Port Driver” and save the file to your hard drive.
- Unzip the USB driver to a directory on your hard drive
- Run “setup” to install drivers

Step 2 – Install Omnicoder Program
- From the BEI download web page, click on the “Windows: Omnicoder Program” and save the file to your hard drive
- Unzip the program to a directory on the hard drive.
- Run “setup” to install the Omnicoder Programming software.

Step 3 – Program the Omnicoder encoder
- The program should start automatically. You have finished installing the software and are now ready to program your Omnicoder. (All Omnicoders are shipped pre-programmed for 1024 CPT) Below is a screen shot of the program interface.
PROGRAMMING A NEW RESOLUTION INTO THE OMNICODER

- Using the Omnicoder programming cable, plug the USB connector end into your PC. The red X (No cable detected) should change to a green check mark, indicating that the USB Programming Module was detected. (This may take up to 15 seconds)
- Plug the M18 connector end into the Omnicoder unit. The red X (No encoder detected) should change to a green check mark, and the current Omnicoder resolution will be displayed on your computer screen.
- To change the Omnicoder resolution, enter a new resolution as an integer between 1 and 10000 in the box labeled “Program New Resolution.” Then click the “Program” button. In a few seconds, the new resolution will be uploaded to the Omnicoder. The Omnicoder is now programmed and can be disconnected. To program a new resolution, repeat the above steps.

The software to program the Omnicoder is only available for Microsoft Windows XP and Windows 7. Additional details are available on the Omnicoder Data Sheet.