Design and Operational Considerations for Avago Technologies Transmissive Optical Incremental Encoders

Application Note 1108

Introduction

This application note is for the motion sensing system designer using any one of the transmissive[1] optical incremental encoders made by Avago Technologies. This application note can be used as a reference for the following encoders: HEDS-91XX modules with the HEDX-51X0 code wheels, HEDS-90XX modules with HEDX-61XX code wheels, HEDS-9700 modules with the HEDS-5120 code wheels, HEDS-9200 and 9720 modules with code strips, HEDS-5500 and HEDS-6500 series kit encoders.

The Avago Technologies optical incremental encoders consist of an emitter-detector module used with a code wheel or code strip. Avago Technologies kit encoders consist of the module and code wheel enclosed in a plastic housing. A two channel shaft encoder is a component that translates the rotational movement of a shaft into two electrical signals. A linear encoder translates linear movement into two electrical signals. These electrical signals can be decoded electronically to determine the incremental distance moved and the direction of movement. Additionally, three channel shaft encoders have a third electrical signal that occurs once every mechanical rotation. This signal can be used to mark a single absolute position for every revolution of the code wheel.

Description

A three channel encoder module consists of a single lensed Light Emitting Diode (LED) source, 690-700 nm, an integrated circuit with detectors and output circuitry, as shown in Figure 1. The light is collimated into a parallel beam by means of a single plastic lens located over the LED. Opposite the emitter is the detector. This integrated circuit contains multiple sets of photodiodes and the signal processing circuitry necessary to produce the output digital signals. The standard two channel rotary and linear modules do not output an index pulse.

In rotary shaft encoders, a code wheel with alternating windows (transmissive holes) and bars (opaque section) rotates in between the emitter and detector, causing the light beam to be interrupted. Multiple sets of photodiodes, in the detector, detect the interruptions to the light beam caused by the code wheel rotation and generate a current proportional to the intensity of light falling on them. The photodiodes which detect these interruptions are arranged in a pattern that corresponds to the radius and design of the code wheel. The photodiode outputs are then fed through the signal processing circuitry resulting in analog signals and their complements. Comparators receive these signals and produce the final

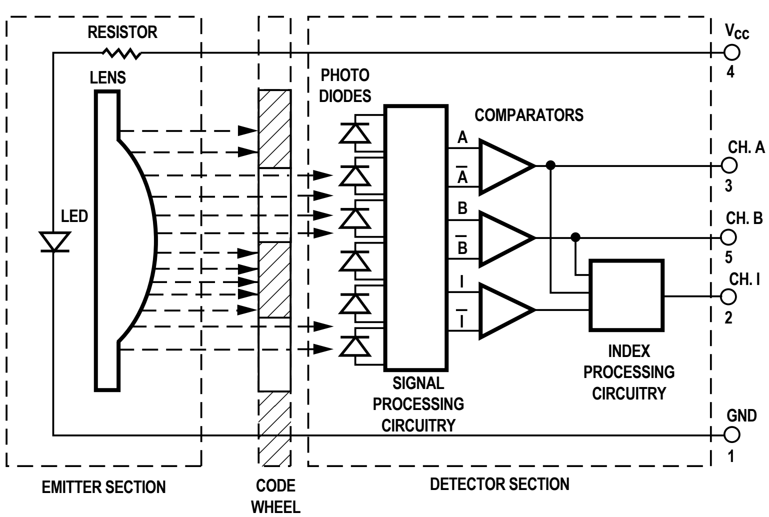

Figure 1. Three Channel Encoder Module.

Note 1. Application Note 1079 describes the design and operational considerations for the reflective surface mount optical encoder.

TTL compatible, digital output signals. The two signals, CH A and CH B, are in quadrature (90 electrical degrees out of phase). This phase shift is different for opposing directions of motion and hence direction of motion can be detected. In 3 channel rotary encoders the index signal, CH I, is an additional signal, 90 electrical degrees wide, that occurs once every rotation of the code wheel.

For linear motion detection, code strips are used in place of code wheels.

Output Signals and Parameter Definitions

Figure 2 shows the signals Channel A (CH A), Channel B (CH B) and Channel I (CH I) for three channel encoders. These signals are TTL compatible. Please refer to the data sheet for electrical specifications for these signals. Two channel encoders have CH A and CH B signal outputs only. Output signal parameters are cycle width, pulse width, state width and phase. CH A and CH B have as many cycles as the CPR specification of the encoder/ codewheel combination. If an index signal is present (for 3 channel encoders) it occurs once for every rotation of the code wheel.

Count (N): The number of bar and window pairs or counts per revolution (CPR) of the code wheel. There are as many cycles on CH A and CH B as the CPR of the code wheel/ module for each revolution of the code wheel. Each cycle (C) has 360 electrical degrees nominally. For a linear encoder the corresponding term is lines per inch (LPI). There are as many cycles per inch on CH A and CH B as the LPI of a code strip/encoder module.

Pulse Width (P): The number of electrical degrees that an output is high during one cycle. Nominally the pulse width is equal to 1/2 cycle and is equal to 180 electrical degrees.

State Width (S): The number of electrical degrees between a transition on CH A and the next transition on CH B. There are four states per cycle and each state is 90 electrical degrees wide nominally.

Phase (Φ): The number of electrical degrees between the center of high state on CH A and the center of high state on CH B. Nominal phase is 90 electrical degrees.

Errors and Design Considerations

As in most measurement systems, the encoding process is not error free. It is important to know the causes of error and understand their effects in order to select a suitable encoder and to define the mechanical requirements of the system on which the encoder will be mounted.

The different kinds of errors and their definitions are as follows.

Cycle Error (ΔC): An indication of cycle uniformity. The difference between an observed shaft angle which gives rise to one electrical cycle, and the nominal angular increment of 1/N of a revolution. The accumulated cycle error leads to position error.

Pulse Width Error (ΔP): The deviation in pulse width, in electrical degrees, from the nominal value of 180 degrees.

State Width Error (ΔS): The deviation, in electrical degrees, of each state width from its nominal value of 90 degrees electrical.

Phase Error (ΔΦ): The deviation of the phase from its nominal value of 90 degrees electrical.

Table 1 summarizes the different factors that significantly affect encoding parameters.

Eccentricity of the code wheels is due to a radial offset of the code wheel pattern. The radial offset is caused by non-concentric code wheel etching, assembly tolerances of the code wheel on the hub, the offset due to set screw mounting and shaft run-out. Eccentricity is periodic, with the period being equal to one rotation of the code wheel.

Radial play is due to bearing tolerance and uneven loading of the shaft.

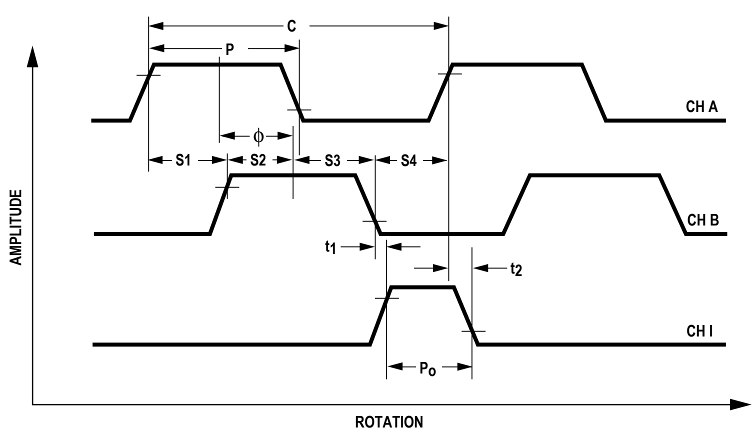

Figure 2. Signals for CH A, CH B, and CH I.

Table 1.

Encoding Characteristic	Eccentricity and Radial Play	Perpendicularity and Axial Play	Velocity	Temperature	Code Wheel Pattern Defects
Position Accuracy	X				X
Cycle Uniformity	X				X
PulseWidth			X	X	X
Phase	X	X			X
State Width	X	X	X	X	X

Figure 3 shows the cycle errors and Figure 4 the position errors for a code wheel with an 11 mm optical radius. The graphs are plotted for a total eccentricity of 0.002".

The position error is calculated using the following formula:

$\Delta P = (e/Rop) \cdot Sin(A) \cdot 180/pi \cdot 60$

where,

ΔP = Position Error in minutes of arc.

A = Angle of rotation, relative to position error of zero

e = Total eccentricity in inches

Rop = Optical radius in inches

pi = 22/7

The cycle error is the rate of change of position error. The accumulation of cycle error is the position error.

Position and cycle error are measured at intervals of one cycle. Therefore, the graph of position and cycle error is not continuous as shown in Figures 3 and 4 but a series of points separated by intervals of one cycle. If this series is connected by a continuous line, it takes the sinusoidal shape shown in the Figures 3 and 4.

High position error would be unacceptable in a pick and place machine. For example, if the move is a fraction of one complete rotation of the codewheel, the measured position is different from the actual position. High cycle error, independent of position error, might be unacceptable for printing a magnetic code strip, because the successive magnetic marking on the code strip is affected by the cycle error. The application therefore determines the error specification for an encoder.

At high frequencies, additional pulse width errors occur due to the differences between the rise and fall times of the output signals.

High Phase Error, Pulse Width Error or State Width Error leads to quadrature loss which results in loss of resolution as well as direction information.

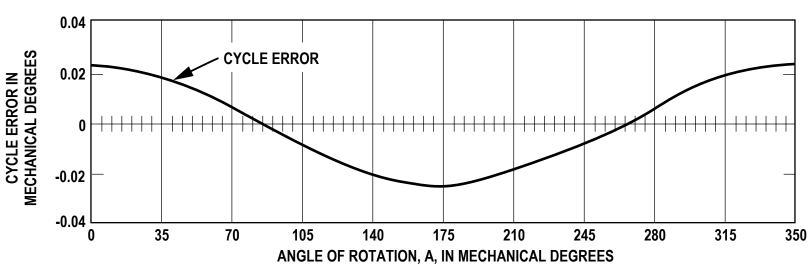

Figure 3. Cycle Error for Code Wheel with 11 mm Optical Radius.

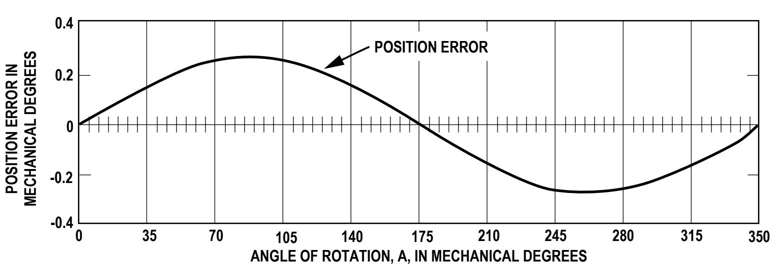

Figure 4. Position Error for Code Wheel with 11 mm Optical Radius.

Statistical Nature of Errors

Errors in encoding can be measured directly after the unit is assembled on a system. It would be useful, however, to be able to predict performance before asssembly so that errors are known in advance and an encoder can be properly chosen for an application. While any single unit's error cannot be predicted with certainty, a statistical treatment will lead to a good approximation of a large batch. A statistical treatment is needed because factors like eccentricty of the code wheel with respect to the hub (controlled by Avago Technologies, for an Avago Technologies code wheel) and, the eccentricity of the shaft (controlled by the customer), that lead to total eccentricity, do not combine in a deterministic fashion to give total error.

When two or more factors combine to form a third parameter, their errors can combine vectorially or algebraically. In a vectorial combination, the resultant error could be more or less than the original errors. For example, the eccentricity resulting from random assembly of a code wheel with eccentricity with respect to its hub and an eccentric shaft is a vectorial combination. An algebraic combination occurs when two errors always make the resultant error larger as is the case when the pulse width error combines with the phase error to produce state width error.

Avago Technologies characterizes the encoders over a wide range of parameters that affect performance, such as code wheel gap, LED light level, module misalignment, temperature, frequency, and code wheel variation. From the results of characterization, production tests are set up at room temperature and a nominal frequency of 8 kHz to ensure that the data sheet error values are not exceeded over the complete range of operating parameters.

Due to the statistical nature of errors and the different parameters that can affect system performance, in the data sheet, Avago Technologies provides values for the upper limit of error that is not exceeded in any given batch over the complete operating range of temperature, frequency and alignment. In general, data sheets do not provide batch by batch error distribution data.

Error Specifications in Data Sheets

Since there are N cycles per shaft revolution, there are N values for the cycle, pulse width, state width and, phase. This means that there are N values of error for each of these parameters for each encoder. In the catalog, the errors are defined as follows:

Typical Error - The average absolute value for a parameter, over a large batch of encoders, of the maximum error observed for the parameter over N cycles, under operating conditions mentioned in the catalogue.

Maximum Error - The maximum absolute error for a parameter that could be observed under worst case operating conditions.

Design Example

This example serves to illustrate some of the issues that might arise in using optical encoders. It is desired to choose an encoder with a resolution of 0.09 mechanical degrees, operating temperature range of -10°C to 50°C, speed of rotation of a maximum of 4500 rpm, shaft size of 0.25" (tolerance -0.0005"). The encoder module and code wheel should be housed so as to offer protection from dust and mechanical damage. The encoder is meant to be used for an incremental positioning application and the error of resolution should be less than ±0.05 mechanical degrees.

The HEDM-5500 #B06 encoder is suitable for this purpose. This encoder can be operated over a temperature range of -40 to 70°C. The speed of rotation is 30,000 rpm. The shaft diameter tolerance recommended is +0, -0.0007". This encoder has 1000 CPR and therefore with quadrature decoding the required resolution of 0.09 mechanical degrees can be achieved. The maximum (worst case) state width error is specified in the data sheet to be 45 electrical degrees which corresponds to ± 0.045 mechanical degrees and therefore the encoder specifications match the application specifications. Notice that the worst case position error is specified to be 40 minutes of arc. This corresponds to 0.667 mechanical degrees. If the cumulative error is important then this error should be less than the application specification.

The error specification for the encoder is based on the shaft perpendicularity plus axial play not exceeding ±0.007", and, the shaft radial play and eccentricity not exceeding 0.0015". Figure 5 indicates how the shaft perpendicularity, shaft eccentricity, shaft axial play and shaft radial play are measured.

The numerical values for the error described in the example are based on the maximum error values as given in the data sheet. If the encoder is being used at nominal conditions of room temperature, 8 kHz signal frequency, and within data sheet mounting tolerances, errors would be closer to those indicated in the data sheet as "Typical".

If the system can be pre-calibrated, then a table of errors can be created that can be used in actual system operation to calculate the true position. Due to the repeatability of encoder signals there is negligible drift in encoder signals over a wide operating range. This means that the errors are constant and the encoder will always measure position reliably and accurately.

Materials Used

Series	Body	Housing	Lens
HEDS-9XX0	Ryton	NA	Polycarbonate
HEDS-97XX	Valox	NA	Polycarbonate
HEDS-55XX	Ryton	Valox	Polycarbonate

Code wheels and code strips are made of nickel plated copper, nickel, stainless steel, film or glass. Hubs for code wheels are made of aluminium. The detector IC is fabricated using a bi-polar process.

The HEDS-91XX and HEDS-90XX series encoders have gold plated leads and are designed to accept connectors. The HEDS-97XX series encoders are designed for wave soldered attachment to a circuit board. The profile for wave soldering is in the data sheet for the HEDS-97XX series parts.

Reliability data sheets are available for the encoders. Please contact your local field sales engineer for a copy of the reliability data sheet. The encoders have not been characterized for use in a vacuum, radioactive environment or fluids of any kind. Avago Technologies has found that almost all solvents, except water, attack some part or the other of the encoder modules and therefore are not recommended. These include alcohol and freon-based cleaners.

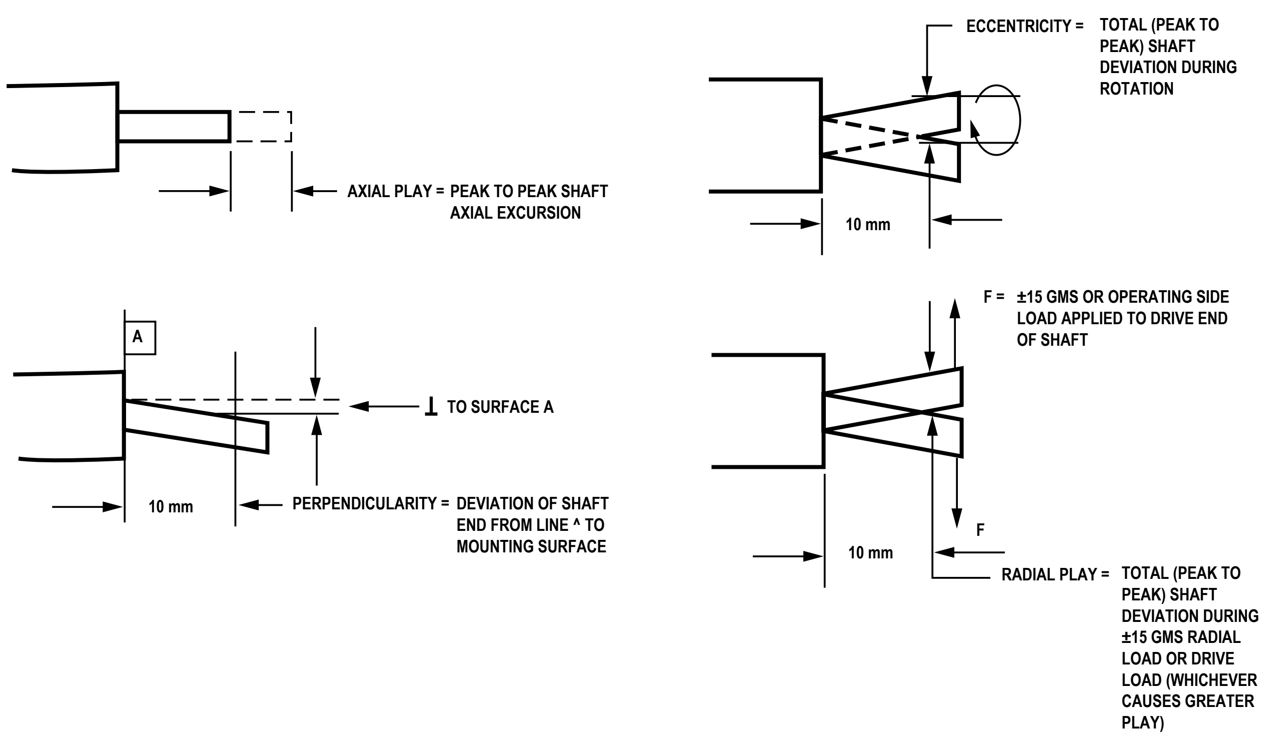

Figure 5. Measurement of Shaft Axial Play, Perpendicularity, Eccentricity, and Radial Play

Interfaces

Avago Technologies offers a series of quadrature decoder counter ICs, the HCTL-20XX, that enable a motion sensing system designer to directly connect the CH A and CH B signals to the IC and use a microprocessor/microcontroller to access quadrature counts from the IC. Figure 6 shows the block diagram of a motion sensing system that uses the HCTL-20XX with a microcontroller.

Please refer to the data sheets for HCTL-20XX for detailed information on the IC. Please contact your local Avago Technologies representative for information about application briefs describing interfaces to the commonly available microcontrollers.

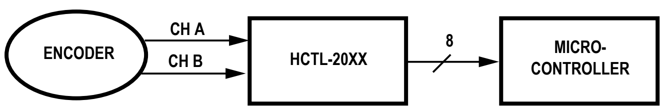

Figure 6. Motion Sensing System Block Diagram.

Motor Manufacturers

A number of motor manufacturers use the Avago Technologies optical incremental encoder modules to provide an integrated motor/encoder solution for end customer use.

Avago Technologies encoders are available through distributors such as Hamilton/Avnet, Arrow, Future, and Newark. For additional information on optical encoders please call your local Avago Technologies sales office.

For product information and a complete list of distributors, please go to our web site: **www.avagotech.com**

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