

# Encoder Simulator Users Guide

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## Introduction

An encoder is a device that works in conjunction with a scale to provide position and velocity information for an axis. The axis can be linear or rotary and the encoder can provide incremental or absolute values. The most common type of encoder used on a CMM are the linear incremental types although absolute and rotary encoders have been used on some machines.

Incremental encoders produce an analogue sine and cosine signal from a scale allowing accurate position tracking of a CMM axis. The data from the encoder is recorded by the controller providing a relative location of the axis from an initial starting position (home position). The direction of the axis appears in the phase relationship between the sine and cosine signals resulting in a CW or CCW angular motion of the encoder signal. The velocity of the axis defines the frequency of the encoder signal.

Scales used on a CMM commonly have a grating period that is suitable for the manufacturing process but not suitable for high precision measurement. To solve this problem the sine/cosine signals from the encoder are interpolated to a far higher resolution than what is available from the scale directly. A typical tape scale that has a scale grating period of 0.100 mm is commonly interpolated to a resolution of 0.001 mm or smaller.

The problem with interpolation of the raw scale signal is that the end result is essentially an estimation. If the encoder signal is poor quality, either misaligned or otherwise distorted, then the interpolation of the signal will produce poor results and affect machine accuracy. The upper limit for interpolation is set by the ability of the electronics to handle the high frequency data at a desired axis velocity.

The Encoder Simulator utility was written to better understand the effects of encoder signal problems by allowing the user to generate various types of input signals and immediately see the effect from an interpolated output over the length of one full scale period. All CMM machines use some form of an encoder that converts a scale signal into a machine position so understanding the issues related to encoders seems paramount when trying to get the most accuracy from a coordinate measuring machine.

A section of this user manual is dedicated to a test process that can be used to evaluate the encoder signal quality using the probe calibration reference sphere. This test can provide an indication of a problem which can then be further investigated if necessary.

This utility is cross platform compatible and can be run on GNU/Linux, OSX, and Windows.

## Overview

The Encoder Simulation utility is a single dialog window with all controls and output displayed on the main window of the program.

The input values to the program allow selection of the scale pitch and interpolated resolution. The scale pitch is the distance of one full scale signal cycle. The interpolated resolution is used to

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determine the necessary subdivision of the input scale signal to achieve the required resolution. Options are provided to manipulate the input sine and cosine gain, offset, and phase that are used by the interpolator to generate a position and direction.

The output shows the effect of interpolating the given input signal over the length of the scale period. The output is derived by simulating an axis moving the distance of the scale forward and then backwards. Counting errors are identified when the recorded distance doesn't agree with the simulated distance moved by the axis.

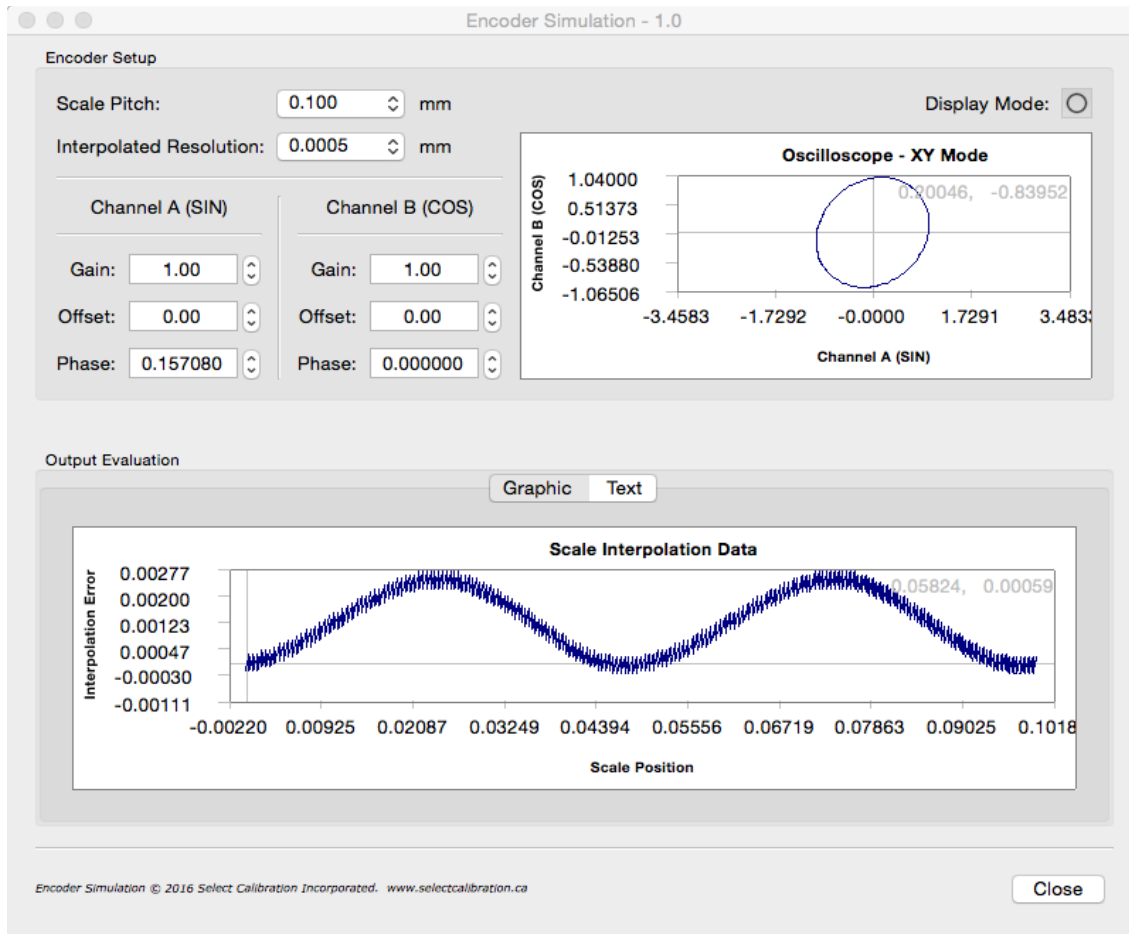


Illustration 1: Encoder Simulation utility program

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## Options

The options used affect the function and display of the displayed data. A description of the options are described in the following sections.

### Encoder Setup Options

Option Name	Description
Scale Pitch	The grating pitch of the scale. For an optical scale this is the distance between the parallel marks on the scale itself.
Interpolated Resolution	The desired scale resolution following interpolation.

### Channel AB Options

Option Name	Description
Gain	This value controls the amplitude of the generated signal. The generated sine and cosine signals are clipped to a maximum value of +/- 1. The signal level can be changed from 0.1 to 2.0 x the nominal input level.
Offset	The signal offset. The sine and cosine values are generated evenly around zero when the offset is zero. The signal can be offset from zero by +/- 1.
Phase	Adjustment of the relative phase of the input channel. This adjustment can change the phase angle of either channel by +/- 1.57 radians (90 degrees).

The manipulation of the AB channel options will appear on the Oscilloscope display. This display can show the data as either a two channel input signal or as a typical XY display of the data depending on the selection of the Display Mode toggle button.

### Output Options

Option Name	Description
Graphic	The interpolated data is displayed visually in a graph.
Text	The interpolated data is displayed in a text format. This data can be copy and pasted into any software suitable for additional analysis of the data.

The goal of the output data is to help identify characteristic error shapes that can arise from different input signals. When testing the encoder signal on an actual CMM the shape of the signal can help pin point the error source by comparing against the simulated signal data.

## Interpolation Method

There are several methods that can be used to convert a sine/cosine signal into a machine position value. Most current CMM's use a method built around the idea of a vector tracking

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conversion. Another method is to use parallel comparators that operate with different input threshold levels. The parallel comparator method is not considered ideal as it is difficult to produce an interpolator where every threshold level is precisely controlled. Although some older CMM's used parallel comparator signal interpolators they seem to have been phased out in favor of newer methods. The vector tracking method is suitable for high resolution and precision due to the single comparator design.

The method used by the Encoder Simulation utility is loosely based on the vector tracking method. A block diagram of the Encoder Simulation program is shown in illustration 2. The key parts of the program are as follows:

- The sine and cosine signal generators produce an output that is controlled by the input gain, offset, and phase parameters.
- The sine and cosine signals are converted to an angle ( $\tan = \sin/\cos$ ). The direction of travel can be determined by monitoring the change in the angular position (CCW / CW).
- The input angle is compared to the current angle stored in the binary counter. When the angle exceeds a set threshold the binary count is incremented or decremented depending on the direction of axis travel.

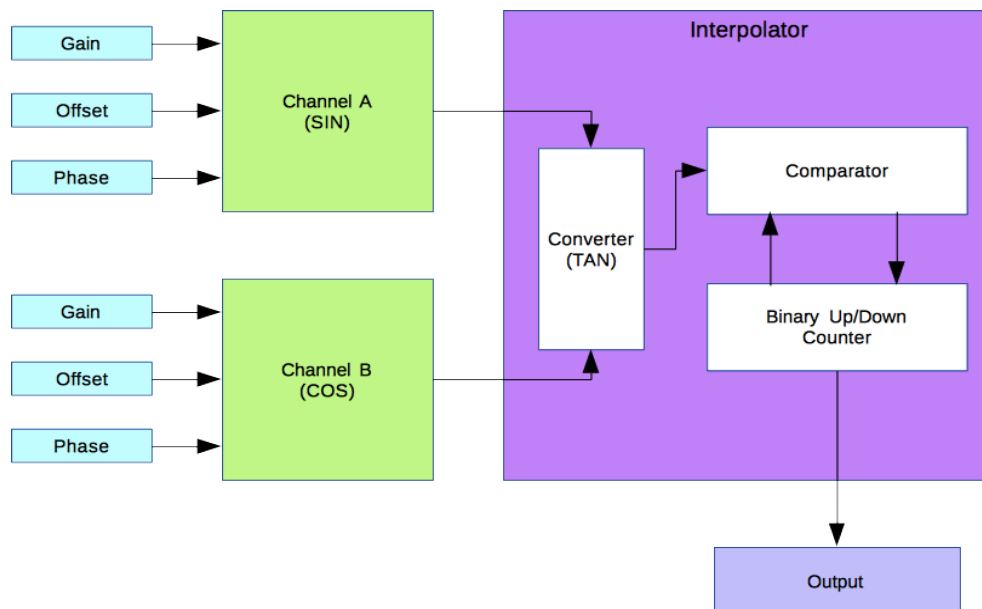


Illustration 2: Block diagram of the Encoder Simulation utility program.

Every effort was made to keep the software version identical to how an electronic version would function on an actual machine. This includes treating the data as an incremental signal and ignoring the shift in the absolute position from changes in direction.

The Encoder Simulation program does not introduce other types of typical signal errors such as signal harmonics or a fluctuating signal amplitude.

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## Interpolator Noise

There is noise produced from the signal interpolator. The noise is a result of converting an analog signal into a digital representation with limited resolution.

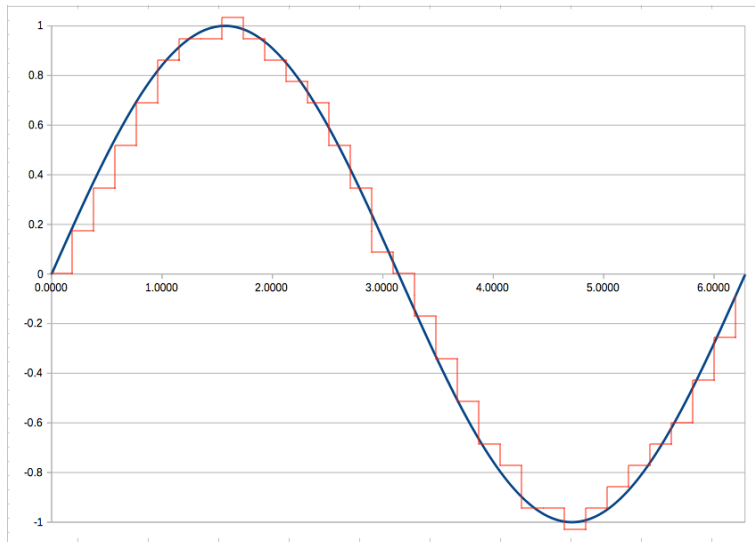


Illustration 3: Noise due to fixed sample points.

The output display is created by testing at a rate of 5x the interpolation level to ensure some of this error is recorded. As the interpolation level increases the noise level will drop as more samples of the input data is used.

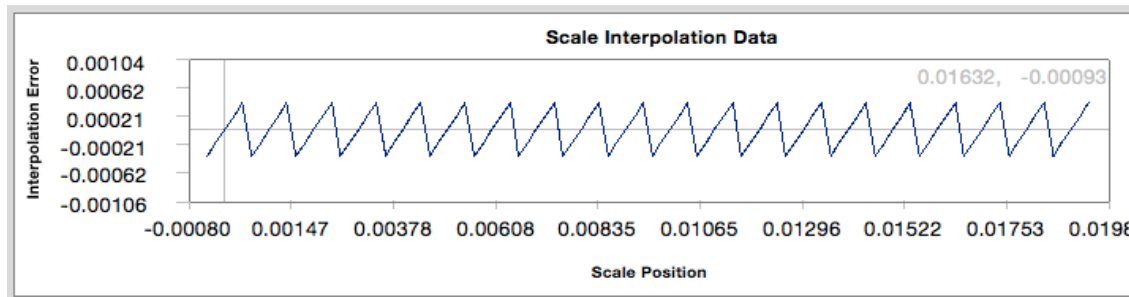


Illustration 4: Interpolator noise as shown in Encoder Simulation utility program.

## Comments

These are some general comments about CMM scales and encoders.

- The type of scales and encoders mounted on a CMM is critical to how accurate the machine will be. Scales with a lower grating period will always be more accurate as less interpolation is required to reach a target resolution.
- Any misalignment of the encoder can contribute a sizable amount of error regardless of the type of scale system. The higher the interpolation level the worse the error will be.

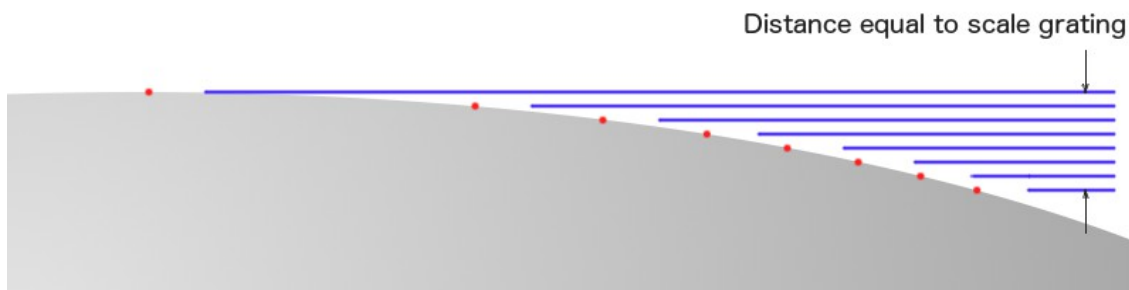
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- Encoder alignment tolerances place a limit on the maximum interpolation that should be practically used.
- Scale interpolation errors are difficult to identify in measurements. A small change in the position of the test artifact resulting in a difference greater than the machine repeatability could be from scale interpolation errors.

## Test Program

It is possible to test the alignment of an encoder on a DCC machine by performing a series of point measurements on the probe calibration sphere. This test involves measuring a series of points where each point has a fixed increment from the previous point along the test axis. The total distance covered would be equal to the scale grating period as a minimum. An example of the measurement pattern is shown in illustration 5.



*Illustration 5: Encoder test program target point example.*

The part program to test the alignment of the encoder would be based on the following method to calculate the measurement target points:

```
for counter = 0 to number_of_steps - 1 by 1

    offset = counter * step_distance
    angle = acos (1 - offset);

    target_point.x = sin(angle) * sphere_radius
    target_point.y = 0.0
    target_point.z = cos(angle) * sphere_radius

    target_point.i = -sin(angle)
    target_point.j = 0.0
    target_point.k = -cos(angle)

end_for
```

The evaluation of the data would involve checking the 3D distance of each point to the center of the sphere. If an encoder problem exists patterns of errors should exist in this data similar to



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how the data appears by the Encoder Simulation program.

Probe compensation is critical for the measured points. Either the probe compensation is disabled in the software resulting in the 3D distance increased by the radius of the stylus or the probe compensation is enable and the proper IJK compensation vector is applied.

Each axis should be tested by moving one of the two perpendicular axis. Both perpendicular axis should be used for each test axis resulting in a total of six sets of measurement data (three axis, two tests for each axis).

When analyzing results the following non-encoder related error sources should be considered:

- Sphere form error.
- Probe error.
- Point repeatability.

These error sources can directly affect the measurement points and indirectly affect the results by not finding the true sphere center.

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## Revision History

Date	Version	Changes
Feb 10, 2016	1.0	New Program