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Laser scale axis referencing with controllers with low bandwidth sine and cosine inputs

Introduction

This document describes the technique used to interface an HS20 laser scale axis to a controller with low bandwidth analogue sine and cosine encoder inputs (such as a Siemens 840D). The document first describes the key differences between a laser scale system and a conventional linear encoder. It then describes the interfacing and referencing sequence both for a single linear axis and for dual linked axes (such as those found on gantry machines).

Conventional linear encoder

Figure 1 below shows a schematic representation of a conventional linear encoder, as might be used on a machine tool, together with its output signals.

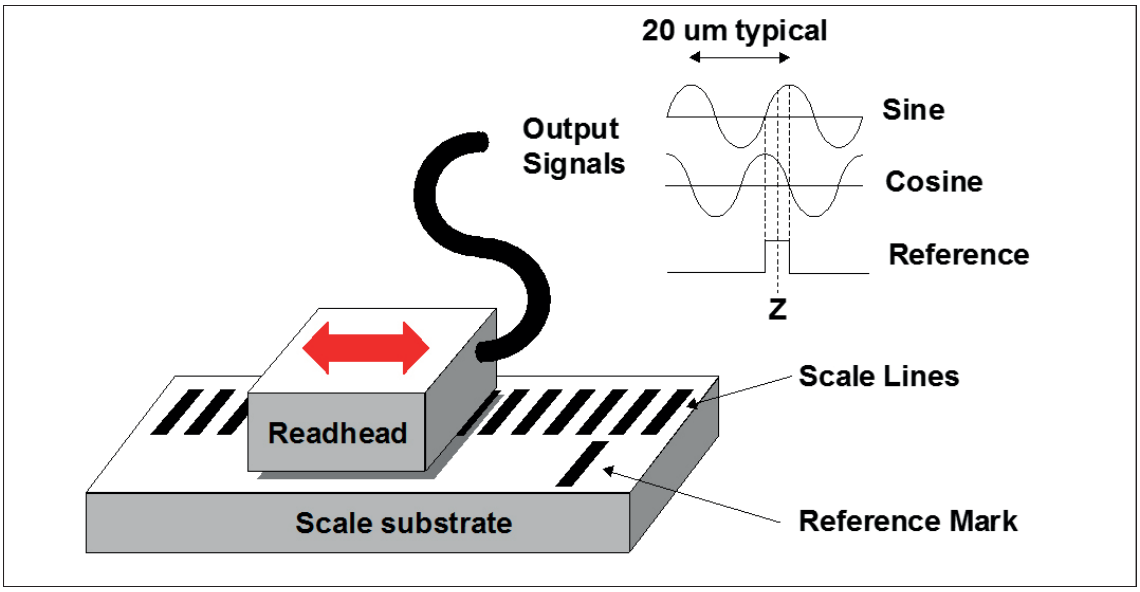

Figure 1: Conventional linear encoder schematic

The key points to note about the conventional linear encoder are as follows:

- Position feedback occurs by detection of the scale lines which are marked on the scale substrate, and which are fed back as sine and cosine signals.
- The scale lines are typically at 20 micron intervals (other spacings are available but 20 microns is typical on metal cutting machine tools).
- The reference mark is formed by an extra line marked on the same substrate and so is mechanically registered with respect to the scale lines.
- The reference mark output signal is phased so that it occurs during the period when the sine and cosine outputs are both positive (this phase relationship is often required by the controller). Note that the home position (Z) actually occurs at the point where the reference mark signal is high and sine = cosine.

Application note

Basic laser scale system

Figure 2 below shows a schematic representation of a basic laser scale system operating without compensation.

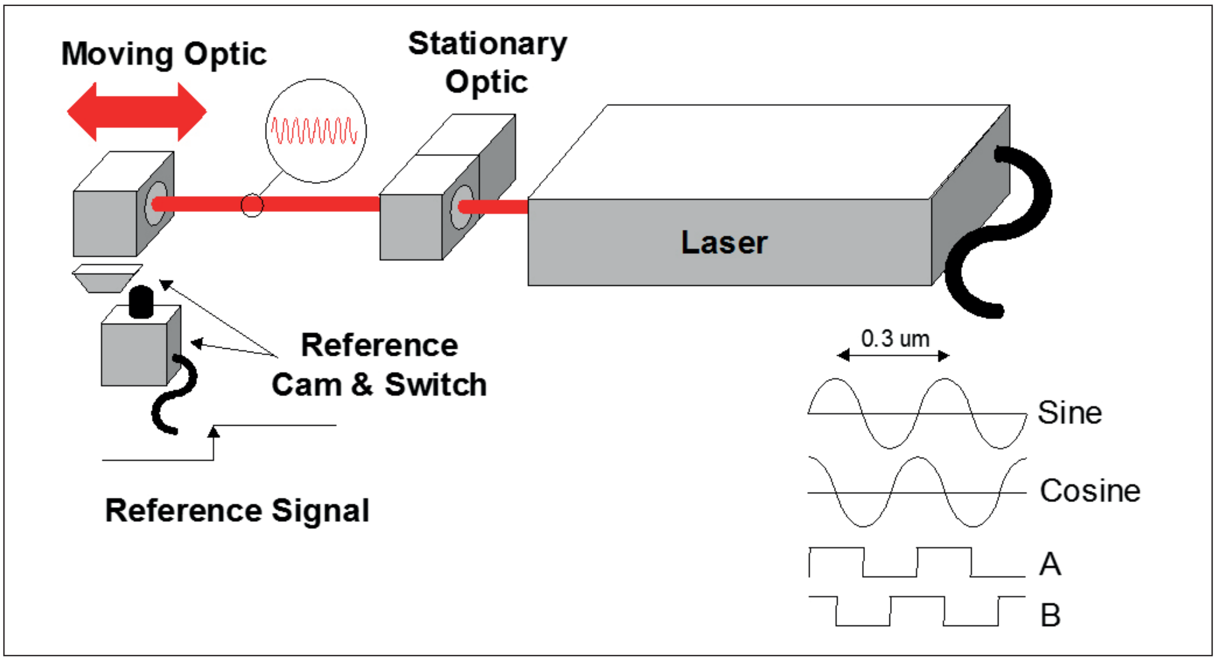

Figure 2: Basic laser scale system (uncompensated)

The key points to note about the basic uncompensated laser scale system are as follows:

- Position feedback occurs by detection of interference fringes formed between the light waves reflected from the moving optic and a reference beam. Movement is fed back to the controller either as analogue sine and cosine waves or as digital A and B quadrature signals.
- The light waves have a very short wavelength of only 0.633 microns. The use of a reflector doubles the sensitivity, so the effective scale pitch is 0.316 microns *(this is about 60 times finer than that from the conventional linear scale shown in Figure 1).*
- A separate mechanical or optical switch is used to provide the reference signal. The exact phasing of the reference signal with the sine and cosine signals cannot be guaranteed because the resolution of the raw laser sinusoids is very high, and because the exact position of the interfering light waves is not mechanically registered relative to the position of the reference switch.
- Although the ***uncompensated*** laser scale offers very high resolution, its accuracy is similar to that of a conventional linear encoder. This is because variations in air temperature, pressure and humidity cause very small variations in the laser wavelength. The effect of these variations can be eliminated using a compensation system (as described in the next section), or by operating in a vacuum environment.
- Many machine tool controllers cannot accept the raw output from an uncompensated laser scale system. This is because the signal resolution is too high for the maximum count frequencies and signal bandwidth of the controller's inputs and because the reference mark signal isn't phased reliably.

Compensated laser scale system

The use of a compensated laser scale system overcomes all the disadvantages of the basic uncompensated laser system described earlier. It also gives outstanding levels of accuracy, and can compensate for work-piece thermal expansion. A compensated laser scale system is shown schematically in Figure 3 below.

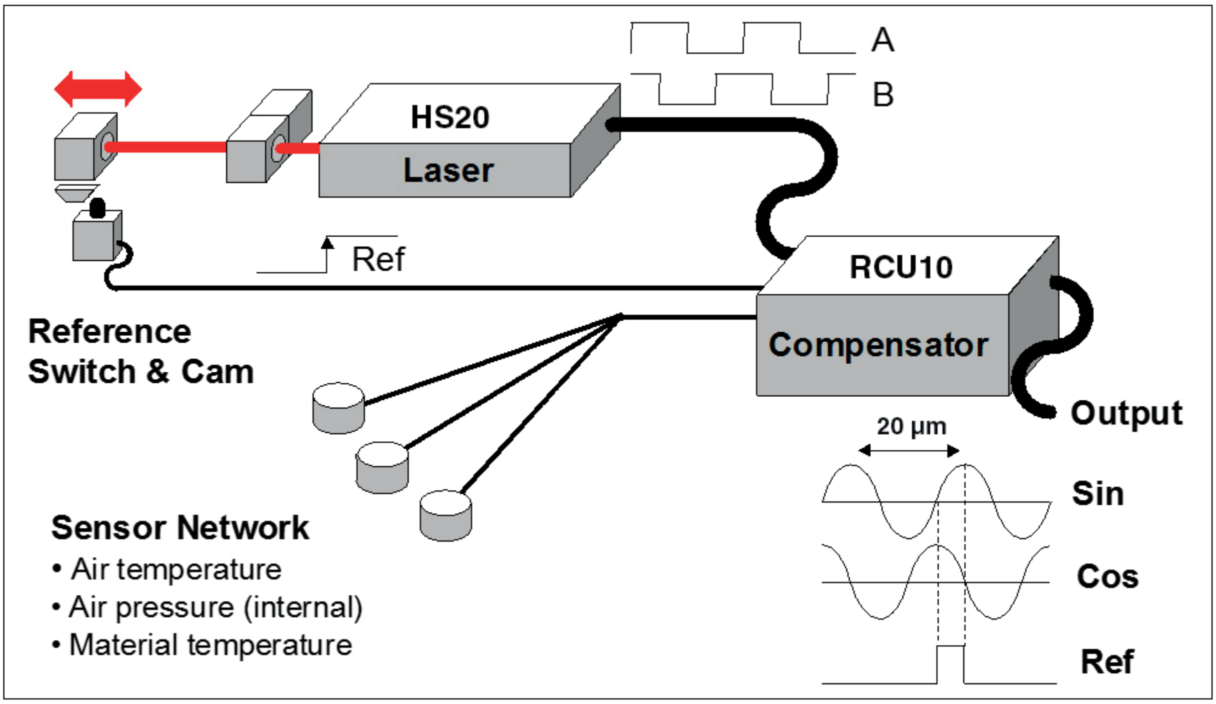

Figure 3: Compensated laser scale system

The raw output from the HS20 laser head is passed through the RCU10 compensation unit before being sent to the machine controller. The RCU10 compensator can provide a variety of different signal output formats and resolutions. However this document describes the configuration used with the low bandwidth sine and cosine controller inputs (such as required by the Siemens 840D controller) on a large machine tool. The compensator is configured to provide the following functions:

- To receive 0.633 micron resolution uncompensated digital A and B quadrature feedback signals from the laser, a reference switch signal and a number of environmental sensor inputs (this resolution of laser output is chosen to minimise the signal bandwidth between HS20 laser and RCU10 compensator, maximising noise immunity on long cable runs).
- To compensate the digital A and B quadrature for variations in laser wavelength (caused by changes in air temperature pressure and humidity), and to compensate for work-piece expansion. This allows the controller to track and correct work-piece thermal expansion. Compensation is performed by real time digital pulse multiplication and addition.
- To synthesise low bandwidth sine and cosine output signals **with a correctly phased reference mark pulse**. In this case the RCU10 compensator is set to provide sinusoidal voltage outputs with a period of 20, 25, 40, 50 and 100 microns. This ensures the output signal bandwidth is kept low and that the waveform is suitable for the controller's interpolation system.

Referencing a single axis

As stated above, one of the key functions of the RCU10 compensator is to produce a reference mark pulse that is correctly phased with respect to the analogue sine and cosine signals. This reference signal must always be produced at exactly the same position on the machine axis, to provide a stable and repeatable 'axis home' position.

In order to achieve this the compensator includes a rephasing circuit that adjusts the phase of the synthesised sine and cosine signals immediately after the reference mark switch is hit, and before the reference mark signal is sent to the controller. The sequence of events is shown pictorially in Figure 4 below.

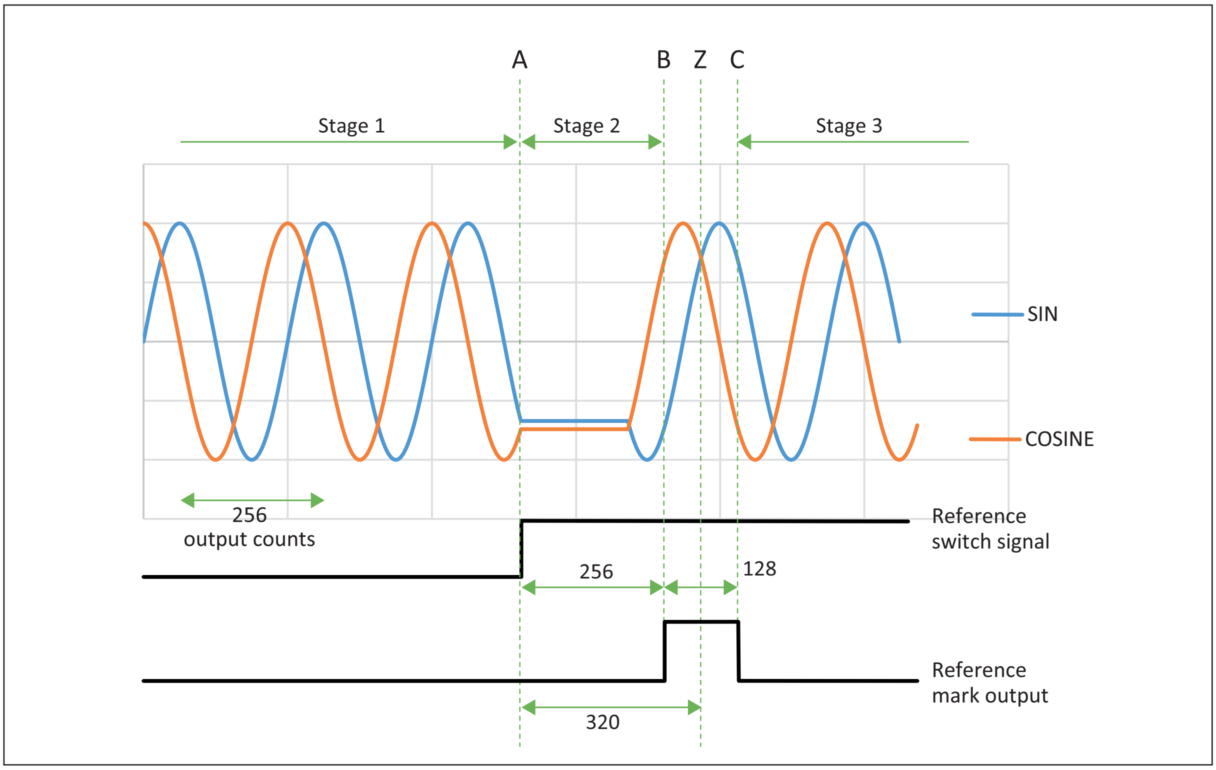

Figure 4: Single axis referencing sequence

The referencing sequence above shows the referencing of a single axis with the controller set to accept sine and cosine signals with a pitch of 256 output counts (20 µm = 256 counts of 78 nm). The sequence of events is as follows;

Stage 1: The axis is not yet homed and is moving slowly towards the reference switch as part of the homing sequence. The pitch of the sine and cosine signals synthesised by the compensator is 256 output counts. At this stage the phase of the sine and cosine signals relative to the axis home position is unknown.

Point A: The reference mark switch is activated. The reference switch signal is received by the compensator ***but is not transmitted to the controller***.

Stage 2: The machine continues to move, waiting for a reference mark signal. During Stage 2 the compensator holds the phase of the sine and cosine signals so that **when the machine has moved exactly 256 output counts beyond the switch**, the sine and cosine signals will be at the correct phase, and a reference mark signal can be initiated and sent to the controller. Note how the compensator has adjusted the pitch of the sine and cosine signals in Stage 2 so that their phase is correct by Point B.

Point B: The machine has travelled exactly 256 output counts beyond the reference switch and the sine and cosine signals are now correctly phased such that the compensator can initiate a reference mark signal and send to the controller.

Point Z: The machine has travelled a further 64 output counts beyond point B. At this point the reference mark signal is active, and the sine and cosine signals have the same voltage. This is the point at which the controller zeroes the axis counter to home the axis. This point is 320 output counts beyond the point at which the reference mark switch was activated.

Point C: The reference mark signal is completed. This is 64 output counts beyond point B.

Stage 3: The machine axis is now homed. The compensator now continues to synthesise sine and cosine signals with a pitch of 256 output counts but it **preserves the phase from now on to ensure accurate feedback of axis movement relative to the axis home position**.

Note on rephasing

During Stage 1, and at the instant the reference switch is activated, the phase of the sine and cosine signal relative to the axis home position is unknown. It will vary depending on where the axis was when the machine was powered up, and could be up to 256 output counts (360 degrees) out of phase.

During Stage 2 the compensator adjusts the phase of the sine and cosine signals. The amount of adjustment required can be anything from +0 to +256 output counts of which is applied over the next 256 output counts of real movement. This additional 'virtual movement' (which is seen by the controller, but not by the axis) **has no effect on axis positioning accuracy, or on repeatability of the home position. This is because it occurs before the axis is homed**.

However, it does have an effect on the homing of synchronised master and slave axes (such as on a gantry machine) if they are homed independently. This topic is covered in the next section.

Referencing a twin axis with conventional encoders

The normal referencing sequence for a twin axis can be described as follows. Suppose the two axes are called X1 and X2 on a twin rail gantry machine and each has its own independent reference switch or mark, and is homed independently.

Axis X1 is homed first, and acts as the master, whilst Axis X2 simply tracks it's movement.

The roles are then reversed. Axis X2 then becomes the master and is homed, whilst Axis X1 acts as slave and simply tracks the movement of X2.

Once both axes have been homed Axis X1 reverts to being the master.

The actual positions of X1 and X2 (relative to their respective reference positions) are now available to the controller.

The controller checks the difference between the positions of X1 and X2 and compares this with a skew limit. If the skew is within tolerance the controller will then synchronise (or deskew) the two axes such that the difference between X1 and X2 positions is reduced to zero (this may also include a correction for an offset parameter that indicates any real offset between the positions of the two reference marks and is used to trim the machine squareness). If the skew is outside the skew limit an alarm is generated.

Deskewing is achieved by moving axis X2 relative to X1 (all other movements are performed with movements of the two axes locked together).

Referencing a twin axis with compensated laser feedback

The homing sequence is identical to that described above. However the effect of rephasing needs to be taken into account.

Rephasing during Stage 2 of X1 referencing will cause **additional movement** of Axis X2. During Stage 2 Axis X1 will move exactly 256 output counts, but the controller may see anywhere from 256 to 512 output counts of movement (due to the rephasing of the sine and cosine signals), which slave Axis X2 will track. **Therefore X2 can move by up to 256 output counts more than X1 during Stage 2 of referencing X1.**

Similarly rephasing during Stage 2 of X2 referencing will cause **additional movement** of Axis X1. During Stage 2 Axis X2 will move exactly 256 output counts, but the controller may see anywhere from 256 to 512 output counts of movement (due to the rephasing of the sine and cosine signals), which slave Axis X1 will track. **Therefore X1 can move by up to 256 output counts more than X2 during Stage 2 of referencing X2.**

Any additional movements of X1 and X2 during the homing process will be in the same direction, so the total skew introduced (i.e. the difference between the additional movement on X1 and X2) will never exceed +/- 256 output counts. Nevertheless it needs to be understood that after each axis has been referenced, **but before the two axes have been synchronised**, there may be up to +/-256 output counts of temporary additional skew between the two axes. This is normal behaviour of the rephasing and referencing system.

On larger machines this skew should present no problems since the distortion is easily absorbed by the machine structure. However, on small machines (or where axes X1 and X2 are close together) it may be desirable to alter the compensator settings to reduce the pitch of the sine and cosine signals to a lower resolution. This will reduce the maximum skew by a factor.

If this skew can be absorbed by the machine structure, then the skew limit parameter **must be set to more than +/-256 output counts** so that an alarm is not raised unnecessarily. Once this is done the controller will continue the referencing sequence and will successfully synchronise the two axes. **This will remove all the skew introduced earlier and both X1 and X2 will have been referenced correctly.**

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