ScioSense

AS65xx Magnetostrictive Position Sensing

Improving Precision using TDCs

AS65xx application note

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1 Introduction

Magnetostrictive linear encoders use the magnetostricitve effect for position sensing. They consist of a ferromagnetic waveguide, position magnet, a damping zone, a strain pulse converter and a measurement electronics.

A short current pulse is applied to the waveguide and creates a radial magnetic field. The position magnet which is connected to the moveable machine part generates a magnetic field at its location on the waveguide.

The momentary interaction of the magnetic fields causes a torsional strain pulse that propagates the length of the waveguide in both directions. To avoid disruption in the measurement the strain pulse as well as the current pulse are damped at the end of the waveguide. The returning strain pulse in the direction of the measurement electronics is converted into an electrical signal by the pickup coil in the strain pulse converter.

As the speed of the ultrasonic wave is known the time between applying the current pulse and getting back the electrical signal is measured and converted into a linear position measurement system.

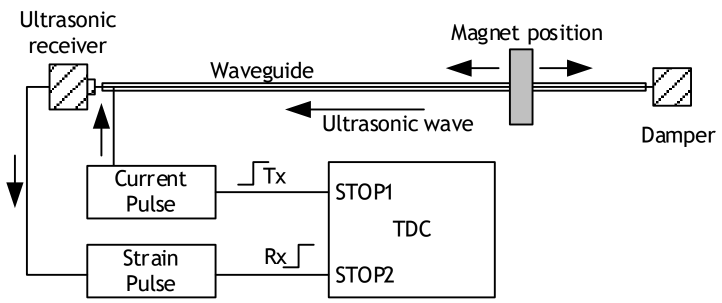


Figure 1: Basic components of magnetostricitve sensor

Components

- Ferromagnetic Waveguide
- Position Magnet
- Damping Zone – wired to GND
- Strain Pulse Converter
- Measurement Electronics

Comparison of Propagation Speeds

Acoustic Wave (340 m/s ... 2,850 m/s) << Electromagnetic Wave (3.00 x 10^8 m/s)

Non-contact, linear position sensing is necessary for many industrial applications. Magnetostrictive transducers in addition offer a very high precision down to 1 µm. They are well established in applications like plastic in-ejection molding machines, hydraulic and pneumatic cylinders or woodworking machinery. A basic challenge for the electronics is high-precision time measurement and can be easily solved using TDCs (Time-to-Digital Converter).

1.1 Application Examples

There are a wide range of applications in many industries for magnetostrictive linear position sensors. Table 1 lists some industries and applications presently incorporating these sensors into their processes and products.

Source on the internet: Magnetostrictive Position Sensors Information. https://www.globalspec.com/learnmore/sensors_transducers_detectors/linear_position_sensing/magnetostrictive_position_sensors

Table 1: Industries and applications using Magnetostrictive Linear Position Sensors

INDUSTRY	APPLICATION
Automotive	Production machinery, on-board suspension, transmission, and steering.
Chip & Wafer Handling	Precision measurement and no wearing parts enable this application.
Electric Actuators	Linear and rotary position can be measured using two position magnets.
Hydraulic/Pneumatic Cylinders	Sensor mounted within the rod and the magnet is fixed to the cylinder.
Food & Beverage	Milk tanks and can filling machines
Liquid Level	Process control, leakage detection, inventory control
Medical	Hospital bed positioning
Metalworking	Measurement & control in forges, presses, bending, and cutoff machines.
Mobile Equipment	Garbage trucks, agriculture, grading and paving.
Paper Converting	Used to control slitters and flexographic presses.
Plastics	Injection molding: injector, ejector and mold halves, also blow molding.
Primary Metal	Walking beams and ladle control
Primary Wood	Sawmills, lathes, cutoff saws, positioning knees, and presses.
Secondary Wood	Saw positioning and tenoners

INDUSTRY	APPLICATION
Testing Equipment	Materials, automotive, military/ aerospace, earthquake and wavemakers

1.2 Comparison of Technologies

There are many things to consider when "designing-in" a linear position sensor. Proper attention must be paid to matching the sensor to the application requirements regarding power input, signal output, housing style, mounting configuration, sensing stroke, and ability of the sensing technology to make the measurement under the application conditions.

With all of these considerations and the number of options available, the task can seem a little daunting. However, here are some of the major product options to consider in Table 2

Source on the internet: Linear Position Sensors Information. https://www.globalspec.com/learnmore/sensors_transducers_detectors/displacement_sensing/linear_displacement_sensors_all_types

Table 2: Comparison of several popular types of linear position sensors

Technology	Resolution[a]	Non-linearity[b]	FSR[c] available	Ruggedness
Magnetostriction	High	Low	10 mm - 20 m	High
LVDT	High	Medium	2 mm - 200 mm	High
Inductive	Medium	Medium	2 mm - 500 mm	High
Encoder	High	Low	10 mm - 2 m	Low
Ultrasonic	Low	High	100 mm - 20 m	Medium
Potentiometer[d]	Medium	Medium	10 mm - 500 mm	Medium

[a] Higher resolution is better, and means smaller steps as the output changes.
[b] Lower non-linearity is better, and means the difference between a straight line and the output.
[c] FSR means Full Stroke
[d] The Potentiometer is a contact-type transducer, all others listed are non-contact

1.3 The Measuring Principle

Source on the internet: Magnetostriction, properties and effects. https://youtu.be/R9CAmjVK3SI

The measuring element consists of a magnetostrictive waveguide. Magnetostrictive materials are elastically deformed when a magnetic field is present. This effect is used in the following manner:

The magnetostrictive waveguide is built as tube with a copper rod inside. The start of measurement is initiated by a short current pulse. This produces a circular magnetic field around the waveguide. The position of the movable part is marked by a magnet whose magnetic field is perpendicular to the circular field of the current pulse. The interaction between the two magnetic fields produces a strain pulse, which travels at sonic speed along the waveguide. A sensor placed at the end of the waveguide converts the sonic pulse into an electrical signal. The travel time is directly proportional to the position of the magnet. The sonic speed in the waveguide is approximately 2800 m/s, which corresponds to approx. 0.36 ms/m. To achieve a resolution of 1 mm, the precision in time measurement must be t = 360 ns!

For example, at a measured distance of 1 meter with a waveguide velocity of 2800 m/s, the time delay would be:

1 meter divided by 2800 meters/second = 0.35 milliseconds

The propagation speed of the wave in the waveguide is approx. 2800 m/s and is quite insensitive to environmental influences. Since the speed of the wave in the conductor v is known (e.g. through calibration) and the time t between the transmission of the current pulse and the receipt of the magnetostrictive echo is measured, the path can be determined approximately according to:

$$distance\ s\ \approx speed\ of\ the\ wave\ v * time\ t$$

As a result, the distance s can be determined with an accuracy limited only by the resolution of the time measurement. Typical arrangements achieve resolutions of approx. 1 µm, corresponds to time t = 360 ps.

Sources of Error

A disadvantage of this method is that i.a. the propagation speed of the wave in the conductor depends on the temperature T of the conductor:

$$v = v(T)\ \alpha \sqrt{T}$$

If no measures are taken to compensate for this deviation, the measurement will become less accurate as the conductor temperature deviates from the calibration temperature (usually room temperature).

2 Time Measurement with TDCs

The table below shows a summary of the differences between current datasheets. Other high-end TDSs are possible.

Table 3: Summary of different current high-end TDCs

	TDC-GPX2	AS6500	AS6501
Input Channel(s)	4x (LVDS / CMOS)	4x (CMOS)	2x (LVDS / CMOS)
Resolution [ps] / High Resolution [ns]	20 / 10	20 / 10	20 / 10
Pulse-Pair Resolution [ns] / Combined Channels [ns]	20 / 5	20 /20	20 / 5
Interface	LVDS / SPI	SPI	LVDS / SPI
Measurement Rate [MSPS]	<70 (peak)	<2	<70
Operating Supply Voltage [V]	2.4 to 3.6	2.4 to 3.6	2.4 to 3.6
Package	QFN64	QFN40	QFP48

AS6500 is a good solution for the time measurement task in magnetostrictive applications. This single-chip time-to-digital converter has 4 channels with a single shot resolution of 20 ps RMS per channel and therefore easily fulfills the needs of high precision positioning.

$$Resolution\ [Bit] = \frac{\ln\left(\frac{Measurement\ Range[s]}{Single\ Shot\ Resolution[s]}\right)}{\ln(2)}$$

$$Measurement\ Range[s] \approx \frac{Maximal\ Distance[m]}{Speed\ of\ the\ Wave[\frac{m}{s}]}$$

$$Resolution\ [Bit] \approx \frac{\ln\left(\frac{Maximal\ Distance[m]}{Single\ Shot\ Resolution[s] * Speed\ of\ the\ Wave\ [\frac{m}{s}]}\right)}{\ln(2)}$$

Moreover, with a measurement range up to 200 ms with same resolution, the dynamic range of the AS6500 is 30 bits. With its FIFO multihit capability, multiple magnets can be handled at once up to the depth of the FIFO. AS6500 is available in a small QFN40 package allowing compact board design.

Calculation of Time Differences

The results of the AS65xx are the time intervals from stop event pulses to the preceding reference clock pulses. In many applications, the time difference between stop event pulses is desired. This happens in the case of a quartz as a reference clock. Depending on the application and the measurement setup, several approaches are possible to calculate the time between two stops in the connected microprocessor or FPGA.

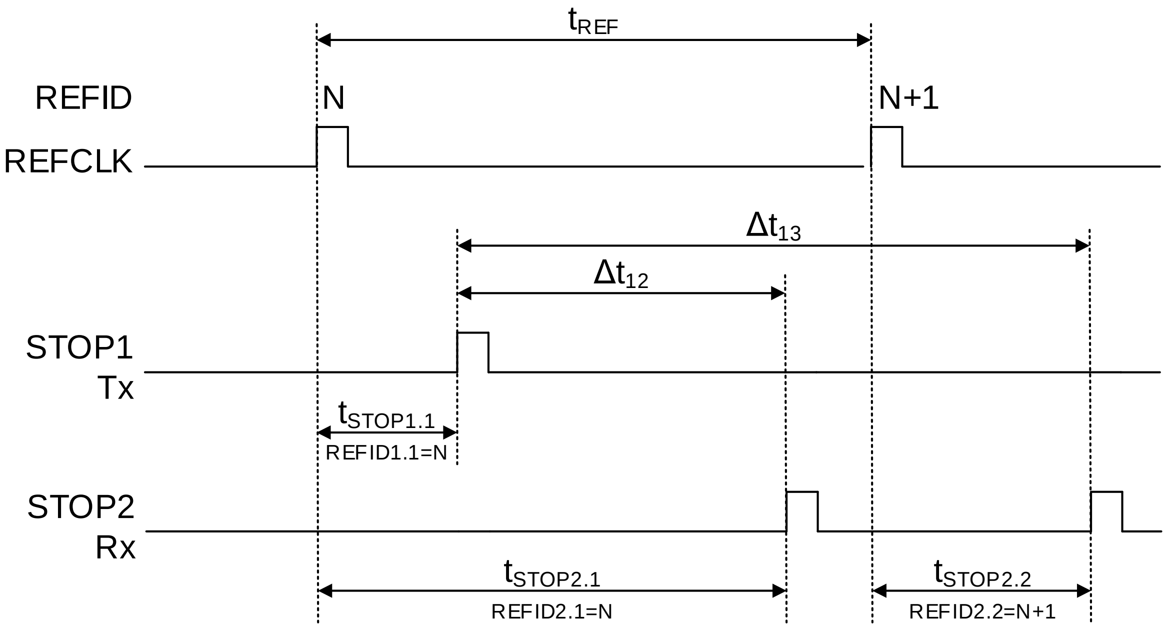


Figure 2: Calculating Time Differences

General Approach

On the output interface, either SPI or LVDS, both data REFID and TSTOP are available. With this data, it is possible to calculate time differences between stops.

In one special case, the reference index of Tx (REFID1.1) = reference index of Rx (REFID2.1), it is not necessary to readout the REFID:

- Stops occur in the same reference clock period

In applications where stops always occur in the same reference period, it is not necessary to read out the reference index. It is sufficient to read out just the stop results and to calculate the difference:

$$\Delta t_{12} = (t_{STOP2.1} - t_{STOP1.1})$$

The maximum time difference depends on the bit width of the reference index (see the data sheet for the AS65xx).

$$\Delta t_{13} = (t_{STOP2.2} - t_{STOP1.1}) + (REFID2.2 - REFID1.1) * REFCLK\_DIVISIONS$$

3 Programming AS65xx

In the following we will show how to program the AS65xx in two different applications.

3.1 Example Code

The example source code is described in our application note (AS65xx Laser Range Finder) and can be downloaded from our website.

Link: < https://www.sciosense.com/products/time-to-digital-converters/as6500-time-to-digital-converter/#documents >

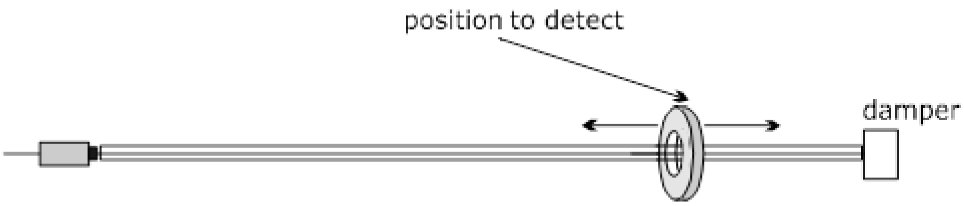
The SPI interface is configured to 20 MHz.

A waveform generator is used to generate 32 reflected pulses (Rx) and is triggered by STM32 (Tx). The STM32 controller also resets the reference index of AS65xx.

The program is split into two main blocks: the configuration routine, where the control registers are set, and the measurement routine

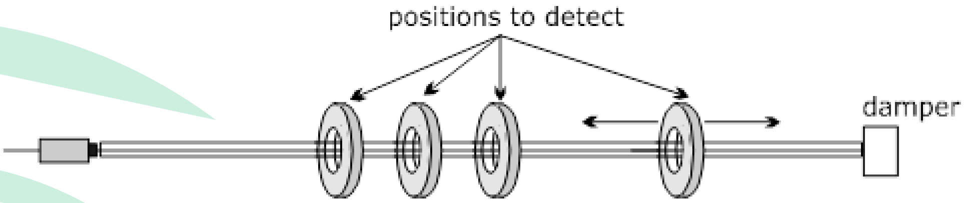
3.2 Measurement example 1

Simple magnetostrictive system with only one magnet, that cannot be removed. The reference clock shall be 2 MHz.



3.3 Measurement example 2

Complex magnetostrictive system with e.g. four magnets. It may be possible to remove any of the magnets. The reference clock again shall be 2 MHz.



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5 Revision information

Table 4: Revision history

Revision	Date	Comment	Page
1	29.08.2022	First edition	All

Note(s) and/or Footnote(s):

1. Page and figure numbers for the previous version may differ from page and figure numbers in the current revision.
2. Correction of typographical errors is not explicitly mentioned.

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