Application Brief

Multi-mover Position Sensing with Linear Motor Transport Systems

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Analog Signal Chain – Sensing

Introduction to Linear Motor Transport Systems

Linear motor transport systems are an emerging industrial application to replace and enhance conventional conveyer-belt-based factory automation systems. Unlike a conveyer belt, where rotating electric motors drive the belt at a certain speed, linear motor transport systems use multiple static, non-moving coil-based linear motor modules to drive magnetic movers, which carry the product to be assembled or processed. There are several system advantages over a conventional conveyer-belt based system.

Due to the versatility of the mechanism, it is now possible to achieve smaller and new geometries of a coil-based linear motor segment modules which include straight, curved, crossing or even two-dimensional movement. Since every linear motor within a segment can be controlled individually, it is possible to drive multiple movers on the same segment at different speeds and positions. For example, one mover stops to process or analyze the product carried by that mover, while the other products on the next movers are traveling on to the next process state at maximum speed. This independent control increases throughput significantly compared to traditional conveyer belt driven systems.

Figure 1 shows a simplified linear motor transport system, with the static linear and curved segments and the movers. Each segment typically includes the *Linear Motor Power Stage* with the corresponding coils to realize multiple 3-phase linear motors, a *Linear Motor Position Sensor* to sense the position and speed of each mover per segment and a *Linear Motor Segment Controller* for real-time position and motion control of the movers. A simplified picture of a mover is shown in Figure 2.

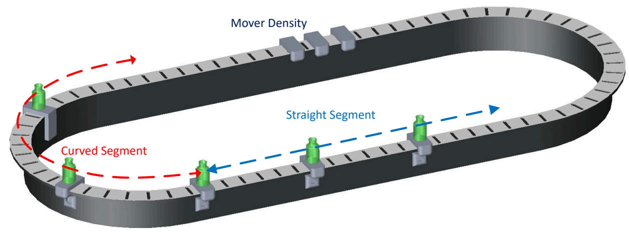

Figure 1. Simplified Linear Motor Transport System with Magnetic Movers

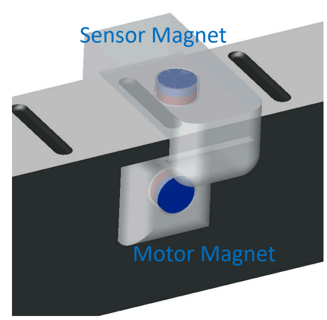

Figure 2. Simplified View of Mover with Sensor and Magnets

Requirements

Linear motor transport systems enable multiple magnetic movers traveling in one or even two dimensions with speeds up to 10 m/s and a linear position accuracy and repeatability as low as 0.01 mm. The magnetic field range present at the magnetic sensor depends on the mover's sense magnet and the distance between the mover magnet to the static multi-position sensor printed-circuit board (PCB). Typically, the magnetic field ranges from 50 mT to 300 mT. Due to space requirements, small packages with highly integrated 3D hall sensor system-on-chip (SoC) are an advantage. An ambient operating temperature of the sensor beyond 85°C, such as 125°C, enables higher power densities, while still capturing accurate sensor data under these extreme conditions.

Since the position of multiple movers within one segment need to be detected at the same time, simultaneous sampling and low latency position measurement are important. 3D Hall-effect sensors with low latency digital interface offer an advantage over analog output SoC due to higher robustness against noise. Further advantages of an SoC with digital interface is the option to integrate diagnostics and monitoring of the SoC, for example die temperature, hall element or supply voltage diagnostics to increase system reliability.

Table 1. Example Requirements for Magnetic Sensors within a Linear Motor Transport System

Parameter	Example value	Impact to position sensor SoC
Mover speed	up to 10 m/s	Impacts sensor sampling rate, closed loop position control frequency can be 4 kHz or higher.
Mover position accuracy/repeatability	as low as 0.01 mm	Impacts sensor resolution, accuracy and minimum displacement between adjacent sensors.
Sensor technology	3D/2D hall sensor	3D hall sensors enable two-dimensional position sensing.
Sensor magnetic field range	50 mT … 300 mT	Full-scale magnetic field strength linear input range
Sensor resolution	Typical 12-bit resolution	SoC with programmable magnetic field range adjustment allow adjust input range for each axis and help increase resolution and accuracy.
Sensor interface	Analog or serial digital	Interface to MCU
Sensor latency	as low as 100us	Higher speed SPI, for example 10 MHz SPI help reduce system latency.
Simultaneous sampling of multiple mover's position	Sensor with low-jitter start-of-conversion capability.	Sensor with hardware pin or SPI command based start-of conversion signal input.
Sensor solution PCB area	As small as possible.	Integrated 3D hall SoC with digital interface enable smaller system footprint.
Operating temperature range	Small form factor and high-power density lead to higher temperature inside a segment.	3D hall SoC with greater 85C ambient temperature operating range.
EMC immunity	SPI interface with CRC	A digital interface with CRC offers higher robustness against impulse noise.
System reliability, predictive maintenance and fault detection	3D hall sensor check, supply voltage check, die temperature check, etc.	Enabled through for example sensor with SPI interface and integrated diagnostics.

Solution Approach

Figure 3 shows a solution for linear position sensing with multiple equally spaced high-precision linear 3D hall-effect sensors with SPI interface.

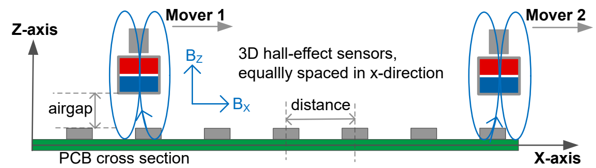

Figure 3. PCB Cross-Section with 3D Hall-Effect Sensor Array

The distance between each 3D hall sensor is system specific and depends on the mover's magnetic strength and magnet diameter, the air gap and the desired position accuracy. Typical distances between adjacent 3D hall sensors are system specific and can be in the range of a few millimeters up to 10's of millimeters. Since the maximum field strength in Z-axis and x-axis can not be identical, a 3D hall sensor which allows for individual range programming and optimization of each magnetic field axis will help support a higher position resolution and accuracy.

Figure 4 shows a system block diagram using the high-precision 3D-hall sensor TMAG5170. A dedicated start of conversion pin ($\overline{\text{ALERT}}$), enables simultaneous sampling of all 3-D hall sensors by the host MCU and enables low jitter synchronization of the position sampling time with respect to the power stage and segment control algorithms.

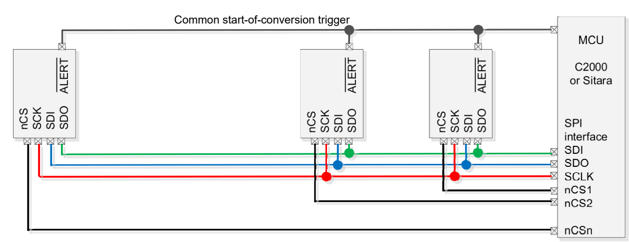

Figure 4. Host MCU SPI Interface to TMAG5170 Sensor Array

The 10 MHz SPI interface with individual chip select for sequential high-speed data transmission minimizes the number of signal traces required to communicate with the host MCU. If the system is to be optimized for absolute lowest latency, it is also possible to independently route the SDO signal from each TMAG5170 data sheet to the host MCU.

The individual linear position of each sensor is then calculated by the host MCU. As a first step, the MCU needs to detect the sensors closest to each mover for example by searching the peak Z-axis values within a sensor array. Next, the Z-axis and X-axis are often offset and gain corrected. Using these corrections, the relative angle between the sensor and magnet can then be calculated by the MCU or using the CORDIC output of the sensor. Optionally, the calculations can be further linearized to optimize position tracking for the mechanical setup.

Figure 5 shows simulated magnetic Z-axis and X-axis magnetic field strength Bz and Bx for an N52 magnet with 10 mm diameter for a displacement of +/-20 mm in x-axis from the 3D hall sensor position.

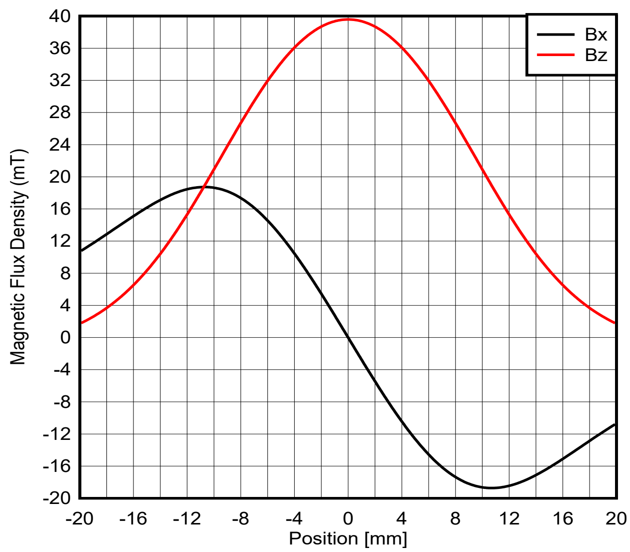

Figure 5. Magnetic Field Inputs for 10 mm Magnet

Calculating absolute position using the magnetic field inputs shown in Figure 5 can yield results with position error that is less than 0.1deg for a range of +/- 13 mm using a simple sensitivity gain and offset correction. Refer to Tracking Slide-By Displacement with Linear Hall-Effect Sensors for more details about the correction algorithm.

The remaining systematic error is related to the non-ideal sine and cosine magnetic fields in both axes and can be further corrected using trigonometric math. However, this more complex analysis is beyond the scope of this report.

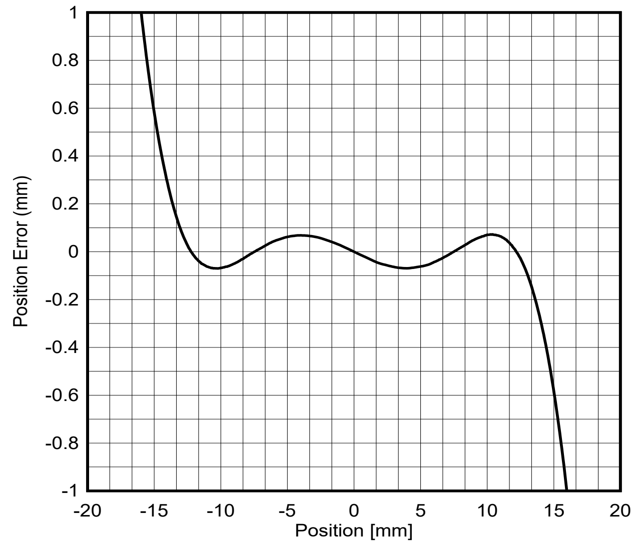

Figure 6. Absolute Position Error for 10 mm Diameter Magnet

Further advantages of the *TMAG5170 High-Precision 3D Linear Hall-Effect Sensor With SPI* 3D hall sensor SoC are related to the various additional integrated features of the device.

TMAG5170 3D Hall-effect Sensor

TMAG5170 is a high precision linear Hall-effect sensor with sensitivity in three axes. The device is highly customizable with the ability to detect each component of the B-field vector using mutually orthogonal Hall-effect elements. This device samples each channel serially and then converts the result using an integrated 12-bit ADC at a maximum sample rate of 20 ksps.

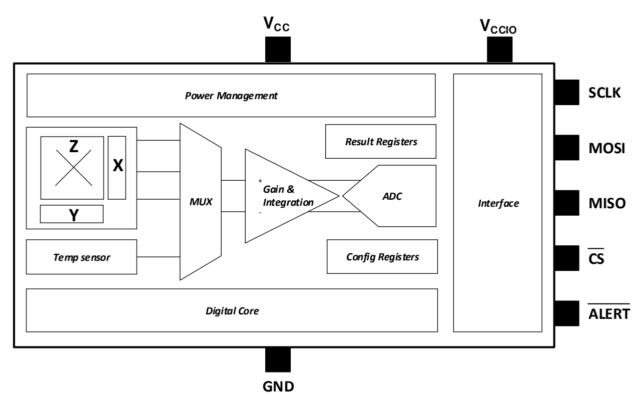

Figure 7. TMAG5170 Block Diagram

Among the many features of TMAG5170 are integrated self-diagnostics, programmable alert thresholds, and customizable triggering for deterministic sampling.

The self-diagnostics of TMAG5170 are capable of monitoring Vcc status, power on reset, output pin status, device memory, temperature, and various other internal checks during live operation. This benefit allows the microcontroller to easily verify each sensor in the system remains operational and helps to flag system level issues that can lead to reliability or safety risks.

There are three triggering modes to initiate magnetic field conversions from TMAG5170. The alert pin of the device can function as an input pin that can be driven by any appropriate IO pin from the host controller. This hardware triggering is convenient and simple. Additionally, the conversion can be triggered through individual SPI command or by the CS pin of the device. With a known trigger timing, the conversion rate of the device can be used to correlate any given measurement to the actual position of the linear mover.

Figure 8 shows an example timing with an 8 kHz position sample rate using the $\overline{\text{ALERT}}$ pin to trigger a new conversion through the host MCU. For this example, the TMAG5170 is configured for pseudo-simultaneous sampling mode of the two axes, Z and X. The effective sample to data-transmit latency is around 60 us.

The SPI transfer of the 32-bit data with the TMAG5170 takes 3.2 us at 10 MHz SPI clock and corresponding setup and hold time, so the overall latency is around 64us when multiple TMAG5170 SDO data lines are connected to a host MCU in parallel. When multiple TMAG5170 use the same multiplexed SDO data line, the overall latency depends on the number of TMAG5170 sensors read out sequentially. The overall latency equals the 60 us plus N-times 4 us to 5 us, when N is the number of SPI transfers including an overhead for the chip select signals setup and hold times.

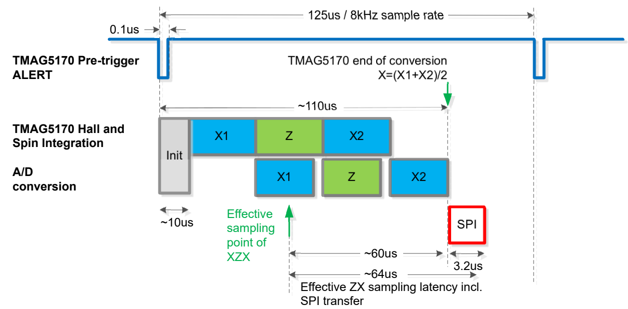

Figure 8. Timing Diagram for 8 kHz Sample Rate Through Start of Conversion Signal ($\overline{\text{ALERT}}$)

One benefit of using either the SPI command trigger or the CS trigger, is that it leaves the alert pin available to provide additional feedback to the controller. When using the programmable threshold limits, each TMAG5170 in the system can provide feedback about the relative proximity of any individual linear mover. By identifying only the sensors which are receiving useful input, the system can implement more efficient SPI reads over arrays of devices.

For more information, please consider the following alternate devices and supporting documentation.

Table 2. Alternate Devices

Device	Description	Design Considerations
TMAG5170 (TMAG5170Q1)	Commercial (Automotive) grade linear 3D Hall-effect position sensor with SPI interface available in 8 pin DGK package	Complete magnetic vector sensitivity over SPI interface. TMAG5170 offers high precision and self-diagnostic features beneficial for system monitoring.
TMAG5273	Linear 3D Hall-effect position sensor with I2C interface available in 6 pin SOT-23 package	Complete magnetic vector sensitivity over I2C interface. TMAG5273 does not offer diagnostic features.
DRV5055 (DRV5055Q1)	Commercial (Automotive) single axis bipolar linear Hall effect sensor with Analog output available in SOT-23 and TO-92 packages	DRV5055 is a one-dimensional linear Hall-effect sensor with analog output. Due to single axis sensitivity, linear array designs would require higher density sensor placement. Analog outputs will require an ADC to sample individual device outputs.

Table 3. Supporting Documentation

Name	Description
Linear Hall Effect Sensor Array Design	A guide to designing sensor arrays for tracking motion across long paths
Tracking Slide-By Displacement with Linear Hall-effect Sensors	A brief discussion regarding linear position calculations for slide-by magnetic sensing
TMAG5170 Evaluation Module for High-Precision, Linear 3D Hall-Effect Sensor with SPI Bus Interface	GUI and attachments incorporate angle measurement using a precise three dimensional linear Hall-effect sensor
TMAG5273 Evaluation Module for Low-Power, Linear 3D Hall-Effect Sensor with I^2C Interface	GUI and attachments incorporate angle measurement using a three dimensional linear Hall-effect sensor
DRV5055 Evaluation Module	EVM incorporates a digital display with various sensitivities aligned linearly along a ruler face.
TI Precision Labs – Magnetic Sensors	A helpful video series describing the Hall effect and how it is used in various applications