

Inductive Sensing Design For Position Sensing in Traction Inverter



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Introduction

Position sensing is of vital importance in the HEV/EV traction inverter system for obtaining rotor angle position and speed. Figure 1 shows the field-oriented control (FOC) in the motor driver system. The rotor angle and speed are two key parameters in the control system.

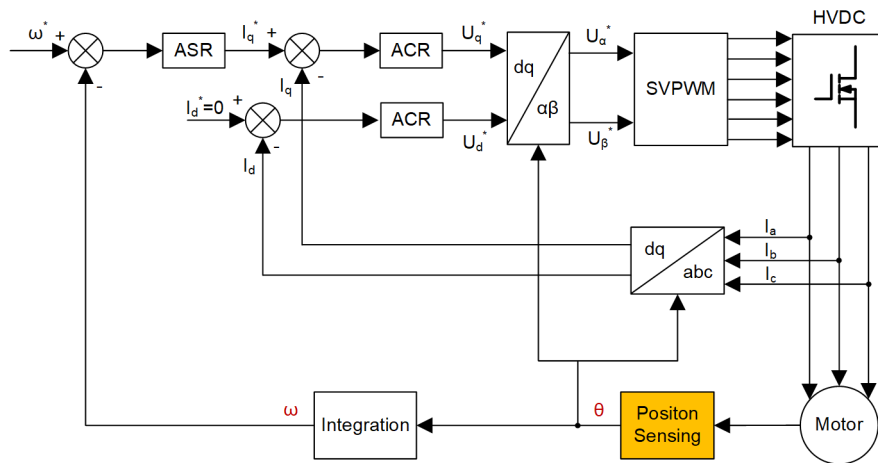


Figure 1. Field-Oriented Control (FOC) in Motor Driver System

In the past, resolver is widely used in traction inverter systems for measuring the angle and speed with high precision, high performance, and high reliability. Recently, inductive sensing designs are a new trend for position sensing with PCB coils fixed on stator and a metal target spinning with the rotor, which can remove the expensive resolver, significantly reducing cost and providing high precision and reliability. Texas Instruments has released the LDC5072-Q1, an AFE IC for contactless, inductive position sensors targeted for absolute rotary position with the accuracy of ≤ 1 degree at rotational speeds up to 480,000 RPM. Table 1 shows some key parameters of LDC5072-Q1 for position sensing.

Table 1. Key Parameters of LDC5072-Q1 for Position Sensing

Parameter	Specification
Input Supply Voltage	3.3V or 5V
Operating Temperature	-40 °C to +160 °C
Electronical Angle Accuracy	<1 degree tolerance at 480,000RPM
Excitation Frequency	2.4MHz to 5MHz generated by LDC5072-Q1
Gain Control	Either Automatic or Manual
ASIL-D Support	2-Channel LDC5072-Q1 for ASIL-D FUSA
Interface	Differential Sine and Cosine Output Without Excitation Frequency

LDC5072-Q1 for position sensing

Figure 2 shows the diagram of the inductive sensing design, including LDC5072-Q1, excitation coil, sensing coils, and target. An LC oscillator is integrated in LDC5072-Q1 for generating 2.4MHz to 5MHz excitation current into the excitation coil. The target (made by Al or Cu) and PCB coils are placed parallel to each other, and there is an eddy current in the target excited by the excitation current, which also generates induced sine/cosine envelope voltage into the sensing coils. The amplitude of the induced voltages are determined by the motor angle position. Then, the sensing signals are demodulated by LDC5072-Q1 and outputs sine and cosine signals to MCU for angle calculation.

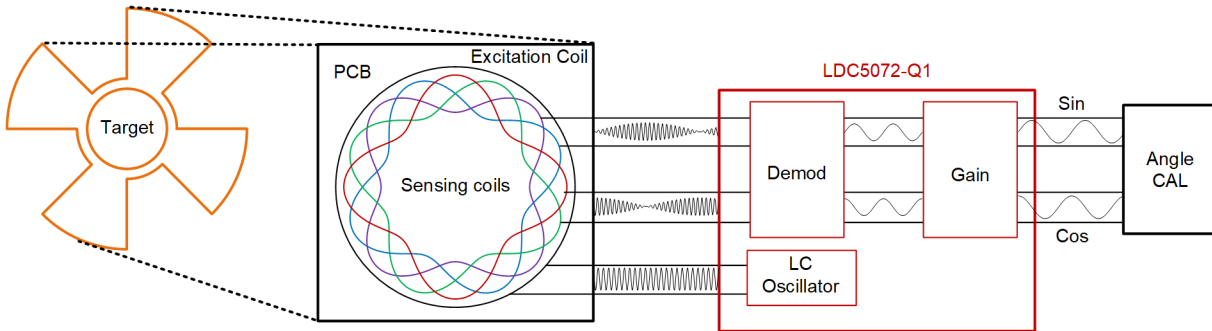


Figure 2. Diagram of the Inductive Sensing Design With LDC5072-Q1

The sensing coils first wrap in a clockwise direction on PCB, and then wrap back in a counterclockwise direction. That is to say, the mutual inductance between the excitation coil and sensing coils are approximately zero. The simplified circuit diagram of the LDC5072-Q1 position sensing system is shown in Figure 3. L_{exc} is the inductance of the excitation coil; L_t is the inductance of the target; L_{sin} and L_{cos} are the inductance of the two sensing coils, respectively. M_{exc} is the mutual inductance between excitation coil and target; M_{sin} and M_{cos} is the mutual inductance between the target and two sensing coils, respectively. f_{LC1} , the frequency of excitation current without target, is determined by the excitation coil inductance and the resonant capacitors, which can be derived from the equation below:

$$f_{LC1} = \frac{1}{2\pi\sqrt{L_{exc}C_1 + C_2}} \quad (1)$$

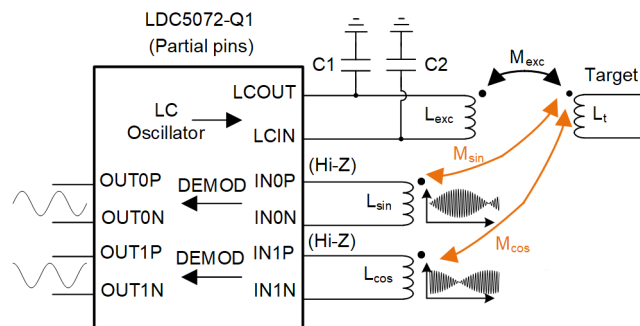


Figure 3. Simplified Circuit Diagram of LDC5072-Q1 Position Sensing System

Where C_1 , C_2 are the external resonant capacitors connected to LCIN and LCOUT pins, respectively. However, when the target and excitation coil approach each other, there is a mutual inductance M_{exc} and this has a little impact on the resonant frequency from the LC oscillator side. Assume the new resonant frequency is f'_{LC1} . Since the coupling coefficient k is much smaller than 1 (k is always range from 0.1 to 0.2), f'_{LC1} is approximately equal to f_{LC1} . Due to the circular shape of the excitation coil, M_{exc} is fixed. M_{sin} and M_{cos} vary with the angle position of the rotor. With the special design of the target and sensing coils, there is a sine envelope and cosine envelope voltages with high frequency excitation signal on the two sensing coils.

Texas Instruments provides an LDC5072 sensor design tool. Customers can input the mechanical and electrical parameters, which generates the Gerber file of the PCB coils automatically. The angle error, inductance of each

coil, mutual inductance between each two coils, and parasitic capacitors are also shown after generating the PCB coils. The sensor design tool is shown in [Figure 4](#).



Figure 4. GUI of LDC5072 Sensor Design Tool

The excitation coil and sensing coils are in the same PCB. The circle excitation coil with multiple turns is on the outer PCB, while the sensing coils are on the inner PCB. The distance between the sensing coil and center of the circle varies sinusoidally, making the output signal a sine and cosine envelope with high frequency excitation signal. The curve function of the sensing coil in polar coordinates is shown in the equation below:

$$\rho = \frac{R_{max} + R_{min}}{2} + \frac{R_{max} - R_{min}}{2} \sin(n\theta) \tag{2}$$

where R_{max} and R_{min} are the maximum radius and minimum radius of the sensing coils, and n is the polar number. [Figure 5](#) show some examples of the sensing coils design in MATLAB.

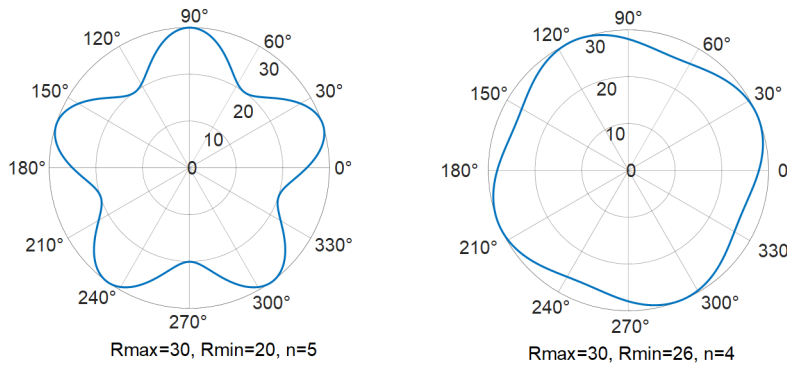


Figure 5. Examples of the Sensing Coils Design in MATLAB

The polar number of the sensing coils and target are equal. The diagram of the sensor is shown in [Figure 6](#). The gray zone is the PCB coil region, where R_{Tmax} and R_{Tmin} are the maximum radius and minimum radius of the target, and R_{Cmax} and R_{Cmin} are the maximum radius and minimum radius of the PCB coil region. To make sure there is the eddy current in target and sensing voltage in sensing coils, the PCB coil region must be in the target polar region, which is also shown in [Equation 3](#):

$$\begin{cases} R_{Tmax} > R_{Cmax} \\ R_{Tmin} < R_{Cmin} \end{cases} \tag{3}$$

With this method, the output voltage of the sensing coils is sine and cosine envelope with high frequency excitation signals, and is demodulated by LDC5072-Q1.

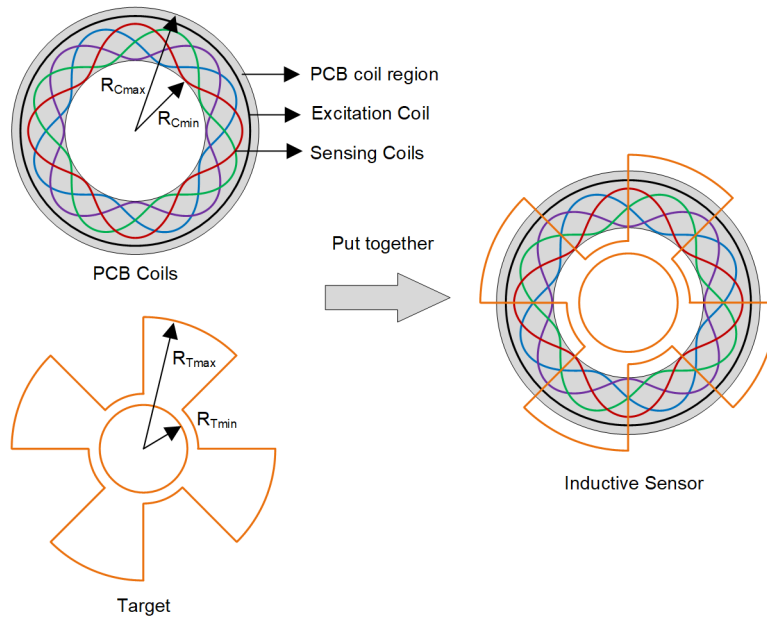


Figure 6. Diagram of the Sensor

LDC5072-Q1 Demo Setup and Performance Compared With Encoder Outputs

Figure 7 shows the LDC5072-Q1 demo for position sensing. Some key materials and parameters are shown in Table 2.

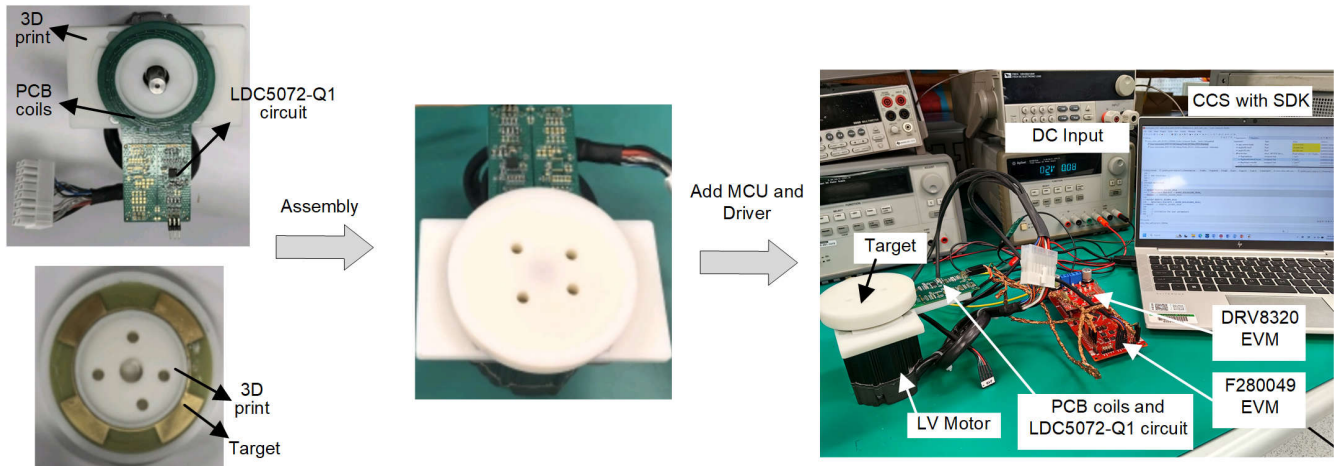


Figure 7. Prototype of LDC5072-Q1 Demo

Table 2. Key Materials and Parameters of the LDC5072-Q1 Demo

Parameter	Specification
Accuracy (System level)	<0.6° mechanical angle error
Motor Speed	150 to 4000RPM
Ratio Electrical to Mechanical	4
Air Gap	about 2.5mm
DC Input Voltage	24V
VCC for LDC5072-Q1	3.3V
Motor Model	M-2310P-LN-04K
Controller	C2000 TMS320F280049C EVM
Motor Driver	DRV8320RS EVM

Figure 8 shows the output signals from OUT0 pins and OUT1 pins with the motor speed at 600RPM. The DC offset of demodulated sine and cosine signals are 0.04V and 0.06V, which are low enough for angle calculation and can be further calibrated by software.

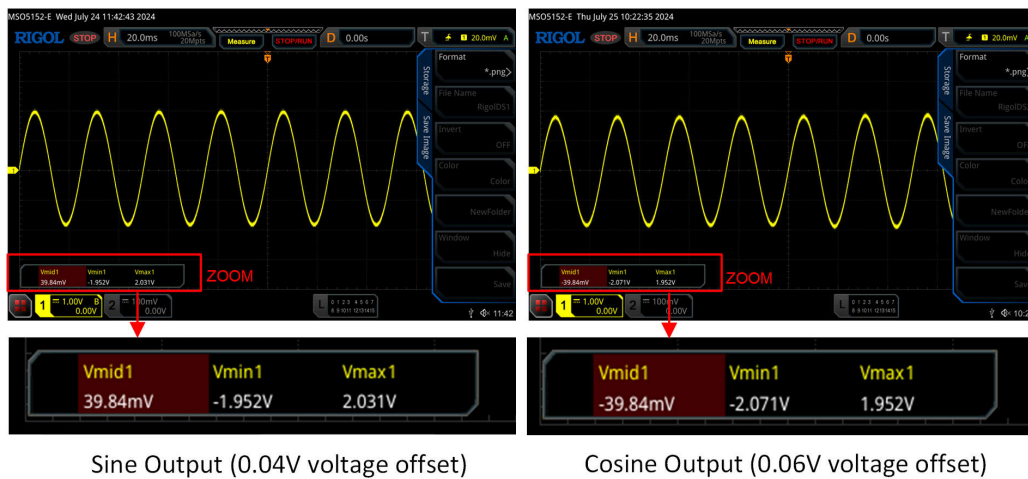


Figure 8. Output Signals of OUT0 and OUT1 From LDC5072-Q1

Figure 9 shows the test results of inductive sensing design and encoder outputs. The accuracy of the encoder integrated in the LV motor is 4000 pulses/r, which can be served as the angle reference of the rotor. With the simple gain calibration, the angle difference between the inductive sensing design and encoder design is lower than 0.6° mechanical angle, which can meet the requirements on motor control and speed calculation.

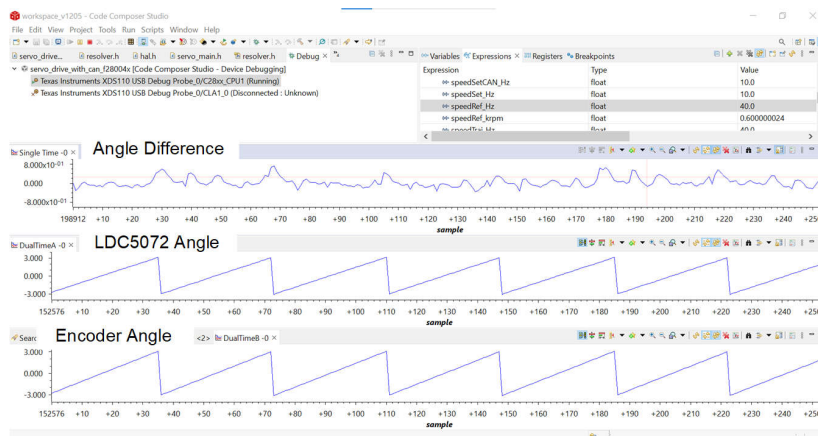


Figure 9. Comparison Between LDC5072-Q1 Design and Encoder Design

Other Materials

- [LDC5072-Q1](#)
- [LDC507X-Sensor-Design-Tool](#)
- [LDC5072-Q1 EVM](#)

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