Resolver interface comparison

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***Abstract*— For control of BLDC motor EMRAX 228 with a peak power of 109 kW, it is necessary to know the exact position in time. This electric motor is used as a drive unit for an electric quad bike manufactured at the Department of Mechatronics and Electronics. In this article we will analyze the position sensing of a BLDC motor with an implemented resolver without an external resolver sensor and with a comparison of two types of resolver sensors PGA411-Q1 and AD2S1210.**

Keywords—resolver sensor, PGA411-Q1, AD2S1210, EMRAX 228, back EMF, comparison

I. Introduction

We chose the BLDC motor EMRAX 228 as the drive unit for the electric ATV and its basic parameters are shown in TABLE I. . The type of implemented resolver is RE15-1-A14. Its basic parameters are shown in TABLE I. TABLE II. . True position of BLDC rotor is basics for BLDC motor control and it cannot be controlled in an open loop like some other motor types. By performing motor control using a resolver, standby current can be reduced significantly, and only the current necessary for the load is consumed. In addition, the heat generation of the motor can be suppressed by reducing the current consumption [1].

TABLE I. BASIC PARAMETERS OF BLDC MOTOR

Maximal battery voltage	680 (HV), 500 (MV),160 V (LV)[a]
Peak power (at 6500 RPM)	109 kW
Continuous power	up to 62 kW
Peak torque	230 Nm
Continuous torque	up to 120 Nm
Efficiency	92-98%

a. HV – high voltages, MV – medium voltages, LV – low voltages

TABLE II. BASIC PARAMETER OF RESOLVER

Pole pairs	1
Input voltage	5 Vrms
Transformation ratio	0.5 ±10%
Input current	58 mA at 7 V & 5 kHz
Phase shift	8° ±3° at 7 V & 5 kHz
Accuracy	± 10' (± 6‘ on request)
Permissible speed	≤ 20.000 min-1
Null voltage	≤ 30 mV
Input frequency	1 & 4.5 kHz

Without the use of sensors, must be use sensorless BLDC motor control methods. Back EMF method, where it use a one phase of BLDC motor for measurement, or like as a sensor. If we look at the switching characteristics of the BLDC motor, shown in figure Fig. 1 and Fig. 2, it can unequivocally determine when it switch an individual pair of BLDC motor phases and on which phase it be measure the back-emf voltage. For a BLDC motor, this is a condition for its proper operation.

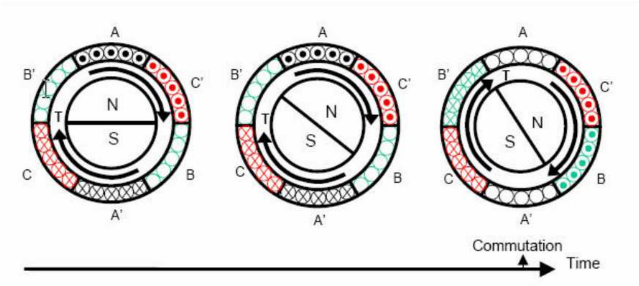

Fig. 1. Operation of BLDC motor [2].

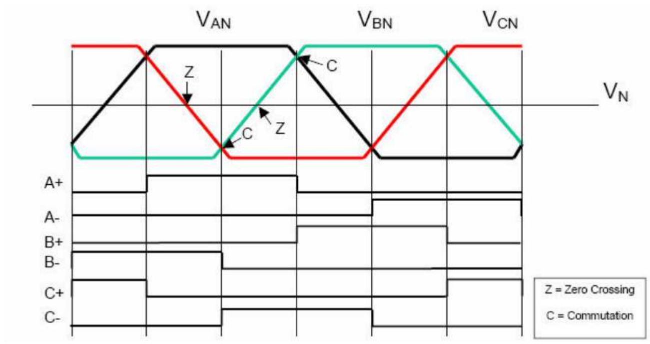

Fig. 2. BLDC motor back-emf and inverter signals [2].

The back-EMF signal from the motor, shown in Fig. 3, must be fed to the input of the microcontroller via a voltage divider combined with a low-pass filter. The purpose of the low-pass filter is to filter out as much high-frequency noise as possible due to PWM control. That filtered signal, shown in Fig. 4, already resembles the theoretical signal from Figure Fig. 2.

This method consists in identifying the moment when the induced voltage crosses zero. This implies that it must be able to measure the induced voltage in the corresponding phase of the motor. In this phase, voltage cannot be generated and measurement of the inducted voltage at the same time. So, from a management point of view, it is necessary that there is always one phase unconnected. For this reason, six step commutation is used for sensorless control.

The principle of measuring the transition of the induced voltage to zero is based on the fact that at the moment when this event is detected and must be recorded this time. From this time, must be calculated the moment of the next commutation and physically switch the transistors. This algorithm is then repeated for the remaining phases.

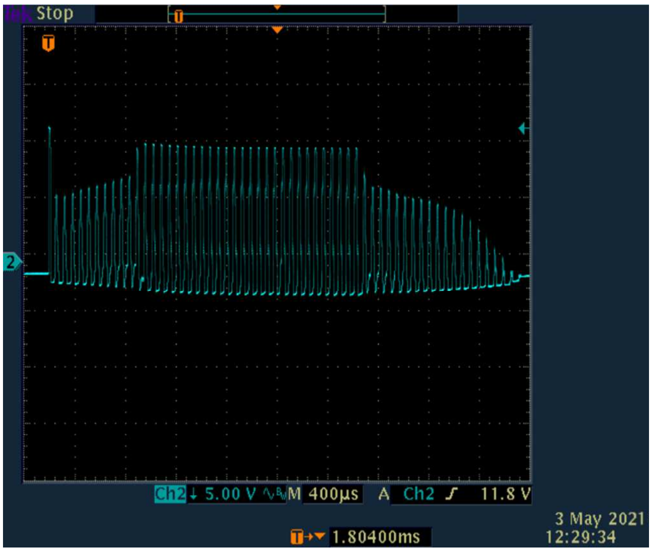

Fig. 3. Unfiltered Back-EMF in one phase of BLDC motor

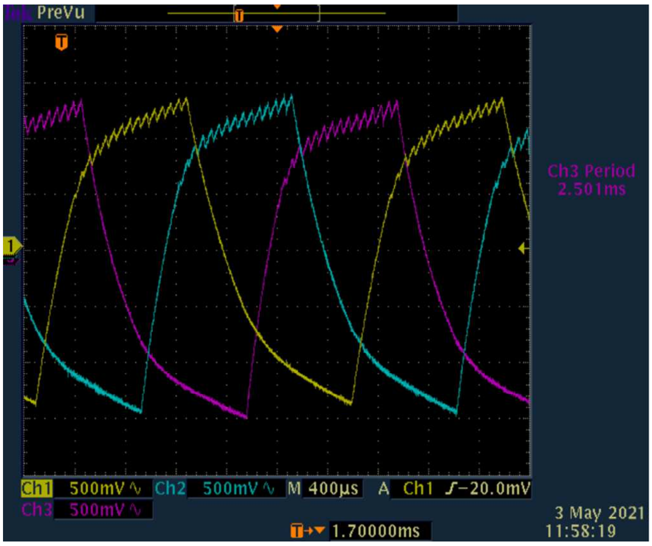

Fig. 4. Filtered Back-EMF in all phases of BLDC motor

II. BLDC MOTOR CONTROL WITH RESOLVER

The resolver consists of three windings. One winding is connected to the rotor and is supplied with a sinusoidal carrier frequency. The other two windings are mounted on the stator in an orthogonal system perpendicular to each other. By rotating the winding with a carrier frequency, a sinusoidal and cosine-shaped return electromotive voltage is generated in the remaining two static windings. By decoding these two modulated signals, it can be get the component cos (φ) and sin (φ), where φ represents the angle of rotation of the rotor. The signal is also generated in a static state, so the resolver is considered an absolute sensor. This is main reason, why is better used sensor method than sensorless and in our case, where it need to be controled the motor torque from zero speed, control without a sensor is impossible.

The resolver is a rotary transformer, with one winding per rotor and two at the stator. For the correct operation of the resolver, must be supplied the winding on the rotor with a sinusoidal voltage, the so-called exciter and then we measure the sine and cosine signal on the stator windings. This is shown in Fig. 5.

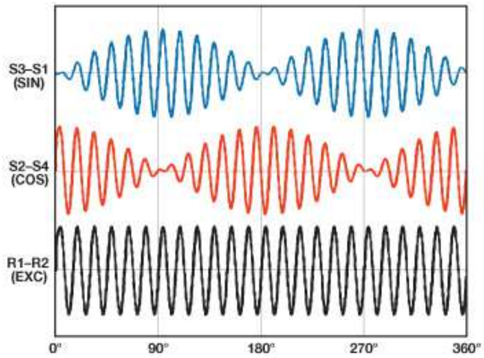

Fig. 5. Resolver electrical signal representation [3].

The mathematical expression of the resolver is as follows:

$$E_0 sin\omega t \times sin(\Theta) \quad (1)$$

$$E_0 sin\omega t \times cos(\Theta) \quad (2)$$

When:

- θ is the shaft angle
- $sin\omega t$ is the rotor excitation frequency
- E_0 is the rotor excitation amplitude

Without the use of a resolver-to-digital converter, it would be had to perform all the mathematical operations in the MCU, which would unnecessarily making these calculations. That's why we decided to use a resolver-to-digital converter. The first is from Texas Instruments and type PGA411-Q1 and the second is from Analog Devices and type AD2S1210. Both of these converters are designed to process signals from resolver. The basic comparison of converters is shown in TABLE III.

TABLE III. RESOLVER-TO-DIGITAL CONVERTER COMPARISON

	PGA411-Q1	**AD2S1210**
Tracking Rate	10/12	10/12/14/16
Input Impedance	25 kΩ	485 kΩ
Operating temperature	–40 +150 °C	−40 +125 °C
Maximum tracking rate 12-bit mode	72 000 RPM	75 000 RPM
Maximum angular accuracy 12-bit mode	±2.64 arc min	±30 arc min
Integral linearity 12-bit mode	±8 LSB	±4 LSB
Comunication	SPI/Paralel	SPI/Paralel
Automotive standard	yes	yes
Parallel-data output update time	100 ns	620 ns [C]

[b.] Circuits parameters are from [4] and [4]

[c.] 10 MHz crystal

Of course, this is a very simplified comparison of resolver processing circuits, but basically TABLE III. shows that both circuits have similar parameters and therefore it can be replaced one with the other.

For position processing from the resolver circuit, we chose a DSP from the C2000 family from Texas Instrument in the version of the 100-foot case. The reason was simple, we required primarily parallel communication with the resolver converter circuit. In both cases, we "missed" for communication and control of the resolver converter approximately 25-30 DSP feet.

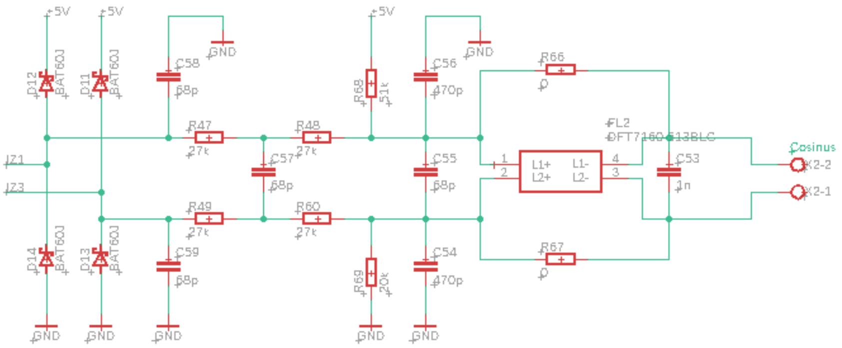

Fig. 6. AFE filter and protection circuit

III. Using the PGA411-Q1 converter

The PGA411-Q1 is a resolver device with a sensor interface with an integrated driver amplifier and a power amplifier. The PGA411-Q1 is capable of running at 10-bit or 12-bit resolution. The internal amplifier power supply for the driver can be used from 10 V to 17 V, which allows the driver output to be set between 4-VRMS or 7-VRMS mode. The integrated excitation amplifier allows up to 145 mA excitation current with exciter frequency from 10 kHz to 20 kHz [4].

The analog front-end (AFE) together with the digital tracking loop performs the function of a resolver to a digital converter. The tracking loop allows the device to support up to 200,000 rpm in 10-bit mode. Each block inside the device has dedicated diagnostics to cover faults. All error conditions are reported via SPI registers with a dedicated FAULT pin that can be used to interrupt the microcontroller unit (MCU) when an error is detected in the system. The PGA411-Q1 has programmable features that allow the system to be flexible when working with a wide range of resolvers [4].

Using the PGA411-Q1 circuit to process signals from the resolver requires 5V and 3V3 power, because the DSP is for 3V3 voltage. The exciter is powered via a simple boost converter. The exciter signal is generated by reading a digital sine wave stored in the device memory and then passed through a 9-bit differentially balanced DAC for generating a differential analog-exciter signal. The exciter frequency signal is from 10 kHz to 20 kHz [4]. The outputs be treated from the exciter with a simple RC filter (68kΩ and 68pF) and diodes protection circuit. This will ensure that the noise at the input to the exciter windings is minimized.

The AFE in the PGA411-Q1 device together with the tracking loop, performs the resolver-to-digital converter functionality. The AFE block connects to the SIN and COS coils of the resolver sensor and signals are amplified by differential input amplifiers with variable gain [4].

The protection and filter circuit from the resolver cosine coil to AFE is shown in Fig. 6 and the entire wiring of the resolver digital circuit in Fig. 7. As you can see in the pictures, it is not a very complicated connection and its individual parts are:

1. PGA411-Q1 circuit
2. Crystal
3. Boost converter for exciter
4. Filter for exciter coil
5. Filter and protection circuit for sinus and cosinus coil
6. SPI communication to MCU
7. Parallel communication to MCU

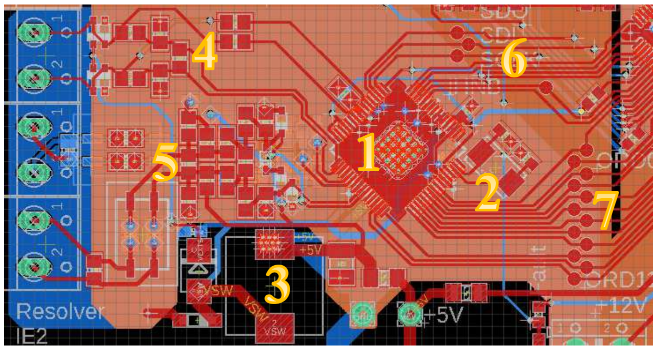

Fig. 7. PCB of PGA411-Q1 resolver-to-digital converter circuit

A. *Hardware tracking loop accelerator*

The analog input signals SIN and COS are multiplied by the feedback SIN and COS from the digital tracking loop. The multiplied signals are subtracted, a control deviation voltage signal is generated. Using a comparator, this signal is converted into digital form and fed into a digital tracking loop. The loop acceleration block helps the tracking loop improve dynamic performance due to effects of high angular acceleration. The converter contains a configurable loop acceleration block with a loop acceleration parameter, DKP (Digital Tracking Loop Gain Constant) and MKP (Digital Tracking Loop Gain Multiplier). By changing the value of the DKP parameter in the register, the tracking loop data is constantly multiplied by the DKP parameter, thus defining the loop acceleration and settling time at any point in operation. The values of the tracking loop are multiplied by both the DKP and FEM parameters until stable loop operation is achieved. Then the angle is updated to the new value and the loop returns to normal operation using only the DKP multiplier.

The advantage of this accelerated tracking mode is the ability of the tracking loop to deactivate the FEM multiplier when the loop is stable and to continue operating with the DKP parameter until another acceleration change occurs or the loop becomes unstable for any reason. Therefore, the use of the accelerated mode significantly shortens the settling time of the loop.

IV. Using the AD2S1210 converter

The AD2S1210 is a complete 10-bit to 16-bit resolution tracking resolver-to-digital converter, integrating an on-board programmable sinusoidal oscillator that provides sine wave excitation for resolvers [4]. The converter accepts input signals, in the range of 2 kHz to 20 kHz on the sine and cosine inputs. The built-in oscillator provides a sinusoidal excitation signal to the resolver driver coil. The excitation output needs a separate external signal amplifier to provide amplitude amplification and sufficient current to control the resolver exciter coil.

The angular position and angular velocity are saved in 16-bit data register and can be taken either via a 16-bit parallel interface or via a 4-wire serial interface. The resolver circuit uses two ADCs to digitize signals from the resolver and convert these signals to digital position and velocity words. The first "amplifier" consists of the ADC gain on the sine/cosine inputs and the gain of the error signal. This is input signal for the first integrator which generates a signal proportional to velocity. The compensation filter is used to provide phase margin and reduce high frequency noise gain. The second integrator is the same as the first and generates the position output from the velocity signal [4].

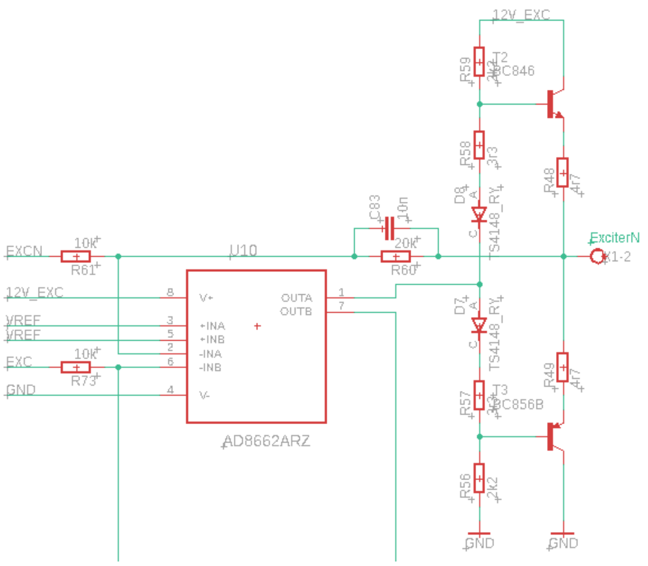

Fig. 8. Amplifier circuit for exciter

The protection and filter circuit from the resolver exciter coil to AFE is shown in Fig. 8 and the entire wiring of the resolver digital circuit in Fig. 9. As you can see in the pictures, circuit for resolver converter is more complicated than previous. Connection and its individual parts are:

1. AD2S1210 circuit
2. Crystal
3. Boost converter for exciter
4. Amplifier for exciter coil
5. Filter and protection circuit for sinus and cosinus coil
6. SPI communication to MCU
7. Parallel communication to MCU

Conclusion

By comparing the two resolver signal processing circuits, we did not want to ultimately show that one or the other company produces better components. Our goal was to find a suitable resolver-to-digital converter circuit replacement for our application, due to the ongoing crisis with semiconductor components. Both circuits are suitable for controlling our BLDC motor, as we do not reach the limit parameters of either circuit.

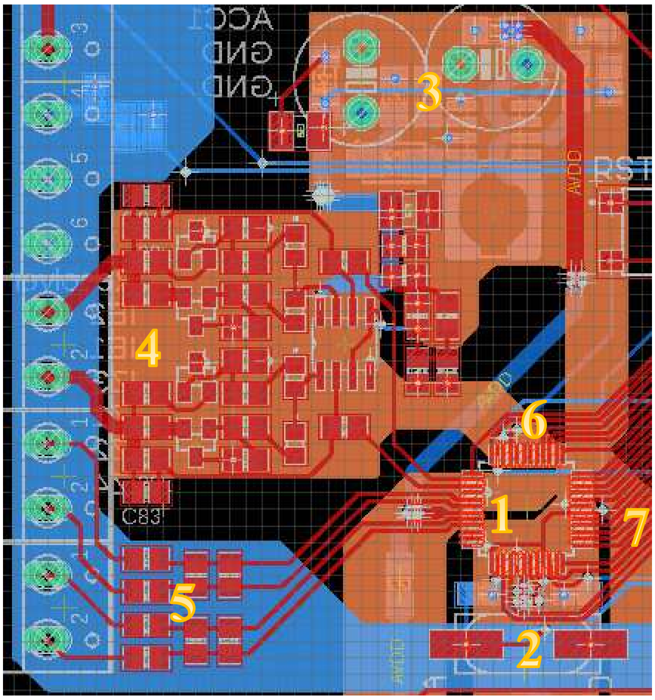

Fig. 9. PCB of AD2S1210 resolver-to-digital converter circuit

Acknowledgment

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