FOC of IM at Very Low Speed Using Low Count Encoders

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Introduction

- In this presentation, contributions to FOC with very low-speed measurement techniques using a low-count encoder will be presented. These contributions are successfully applied to TMS320F28xx based AC drives (FOC) used in golf car industry.

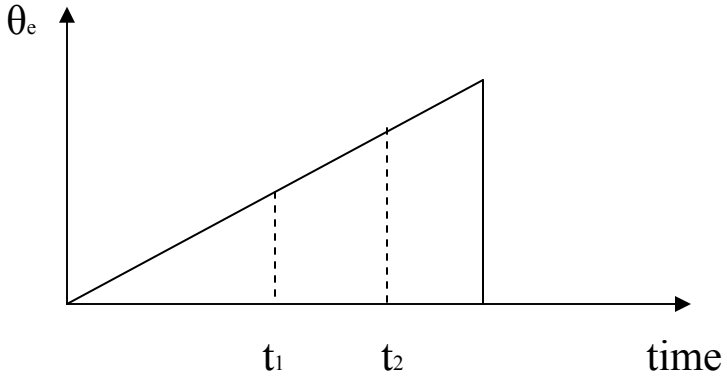
Advantages and Disadvantages of Low Count Encoders

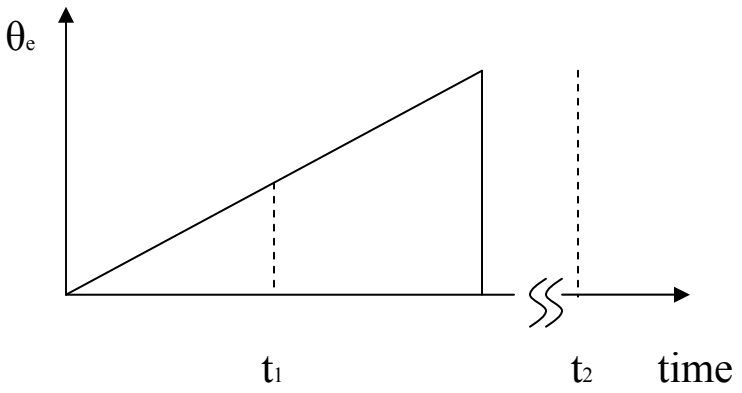
- **Advantages**
  - Low Cost
  - Provides more reliable results when compared to the sensorless FOC application
- **Disadvantages**
  - Low resolution problems at low speed
  - System specific problems

TMS320F28xx Specific Problems & Solutions

Timer-overflow at low speed

- One of the problem encountered in this project is counter overflows at low speed during period measurement between two pulses using CAP units.
- The timers of TMS320F2812 is ~7.5 times faster than F2407. The low speed detection algorithm collapses at low speed range (~below 75 rpm for 28xx and ~below 10 rpm for 24xx) due to counter overflows.
- An overflow detecting and counting interrupt subroutine is added to the speed measurement module to compensate very low speed measurement errors.





$$\Delta t = t_1 - K\,x\,overflow + new\_timestamp$$

TMS320F28xx Specific Problems & Solutions

Rotation direction detection at low speed

- Although the low speed can be measured successfully with CAP Units of 28xx, the direction of the speed cannot be detected.
- In most of the applications, the machine is operated at two quadrant motoring regions. Therefore, the direction of the speed should be known.
- In this project, both of the encoder signal input units of 28xx are employed to measure high speed, direction (QEP) and low speed (CAP) independently.

TMS320F28xx Specific Problems & Solutions

Rotation direction detection at low speed

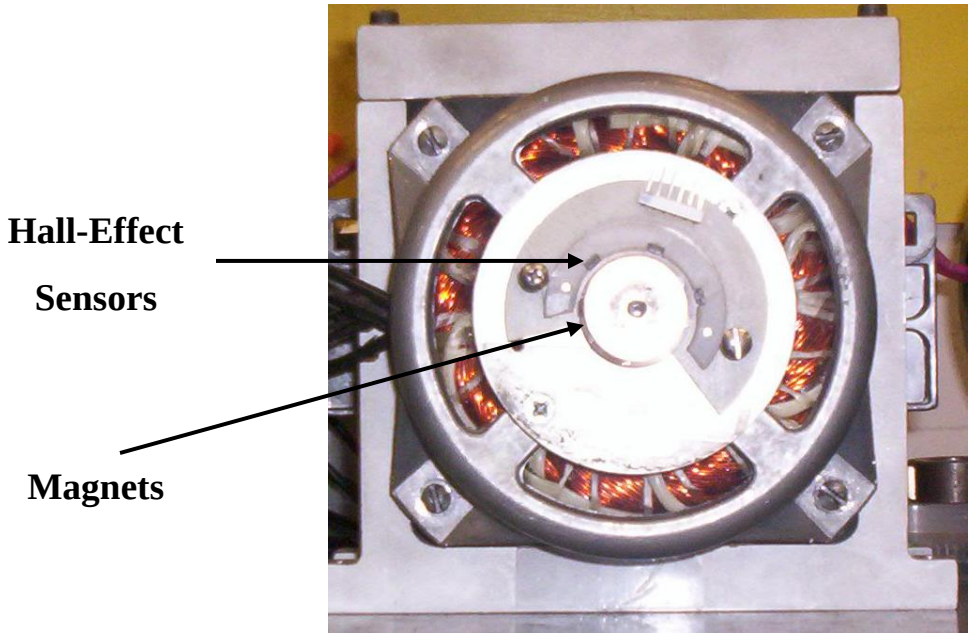
- The direction of the speed is sensed by QEP units and fed back to low speed module. Furthermore, high speed is also computed using QEP units to obtain more accurate results.
- Switching from low-to-high or high-to-low speed measurement modules is achieved by hysteresis characteristics. If the speed measurement algorithms are not toggled from one to another via hysteresis bandwidth, significant noise and spikes are observed at critical transition speeds.
- Different event manager GPOs and registers are employed in the speed measurement modules to prevent speed errors during the transitions.

Variable Pulse (4, 8, 16...etc) Encoder Implementation

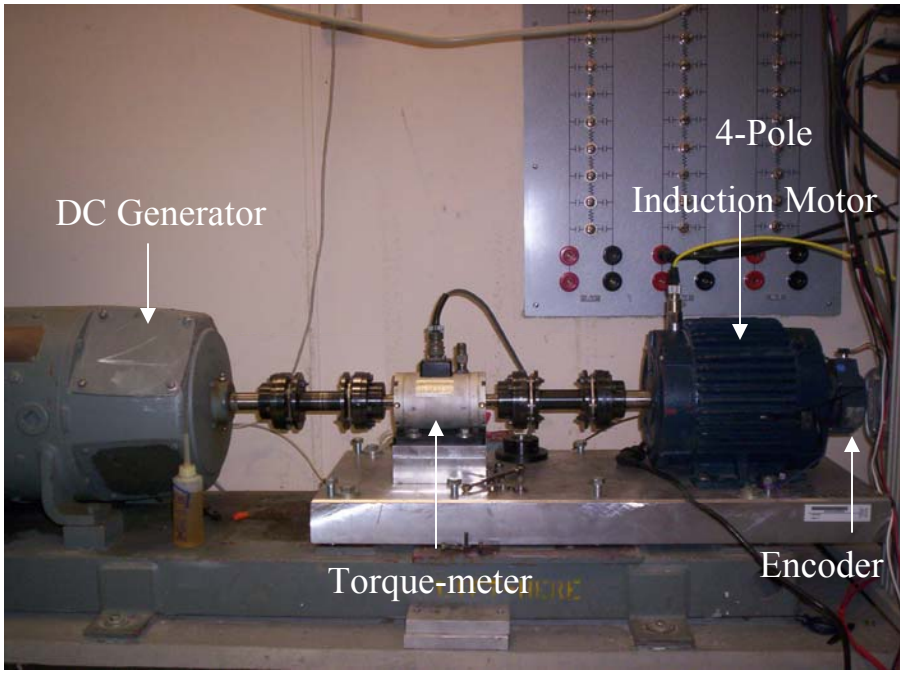
- During the experiments a 2048 pulse encoder is used.
- Both the high and low speed measurement modules are programmed to suppress the encoder pulses to obtain low count encoder output.
- Using this property, the accuracy of the speed measurement modules and the performance of the FOC are tested with different pulse encoder outputs.
- Furthermore, the lowest possible speed with each low count encoders is figured out for stable FOC operation.

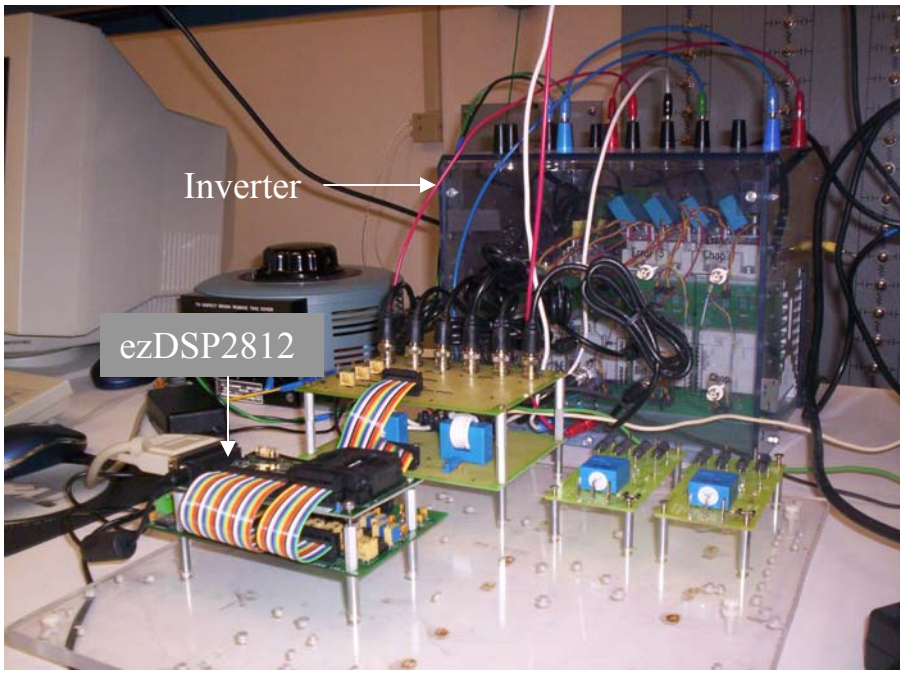
Alternative Low Cost Hall Sensor Applications

- The price of a typical encoder is around $200-300 whereas a hall-effect is around $1-$3.
- In this project, it is shown that a few very cheap hall-effect sensors can be used in FOC of IM applications which have poor resolution (4,8,16 pulse …etc).



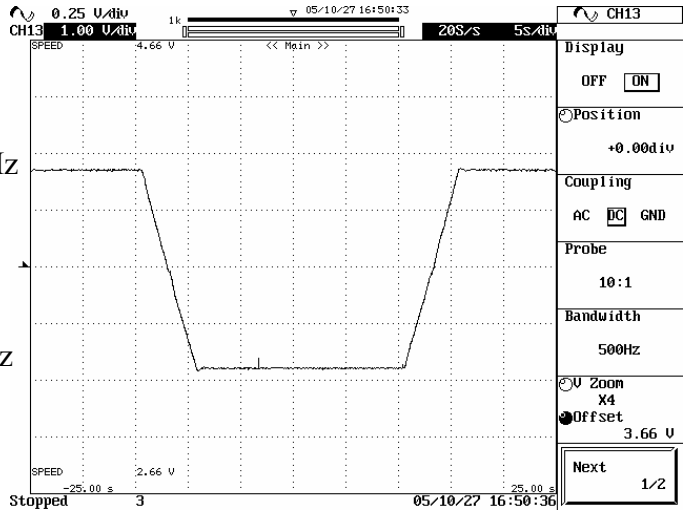
Experimental Setup



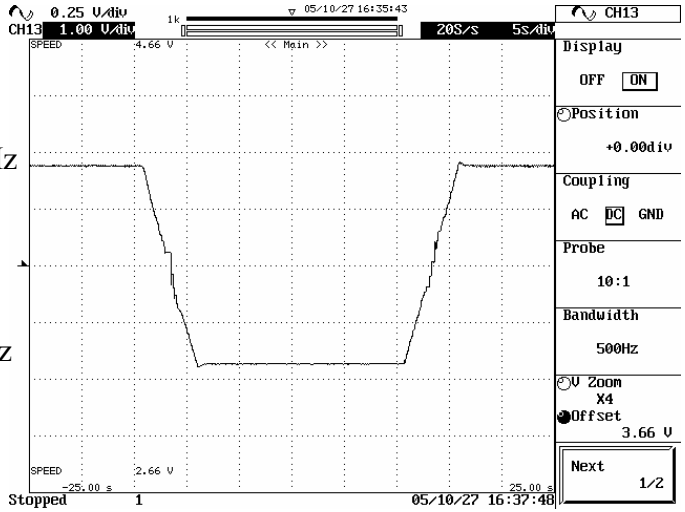


Experimental Results 3-hp IM FOC with Low-Count Encoder Four Quadrant Speed Reversal (±5Hz)

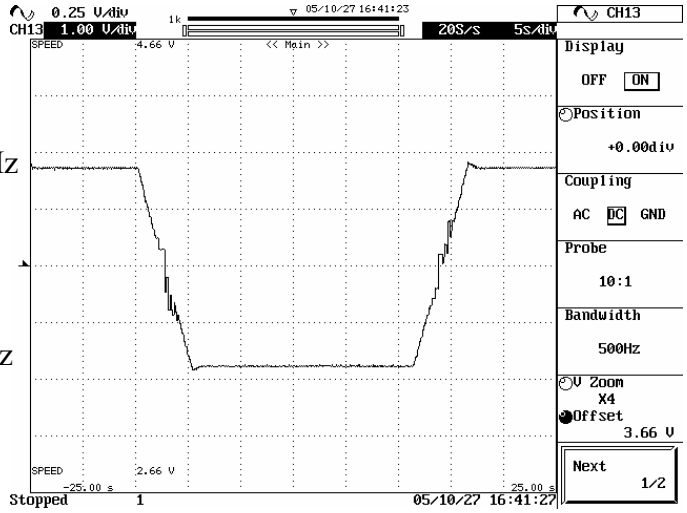
2048 pulse encoder



16 pulse encoder



8 pulse encoder



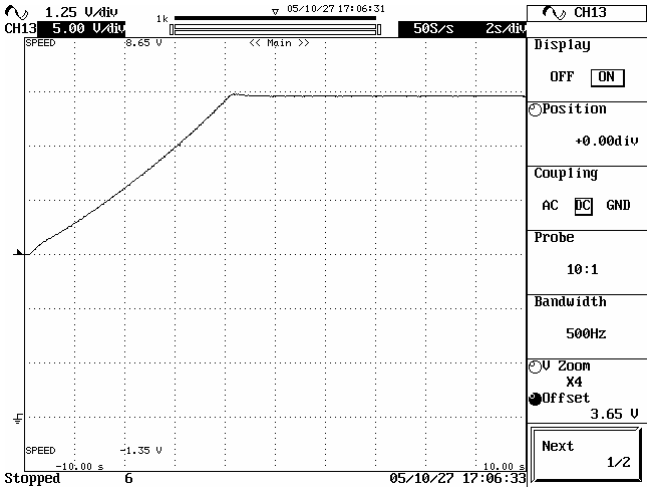
4 pulse encoder

Rotor Speed

Experimental Results 3-hp IM FOC with Low-Count Encoder Start-up Performance

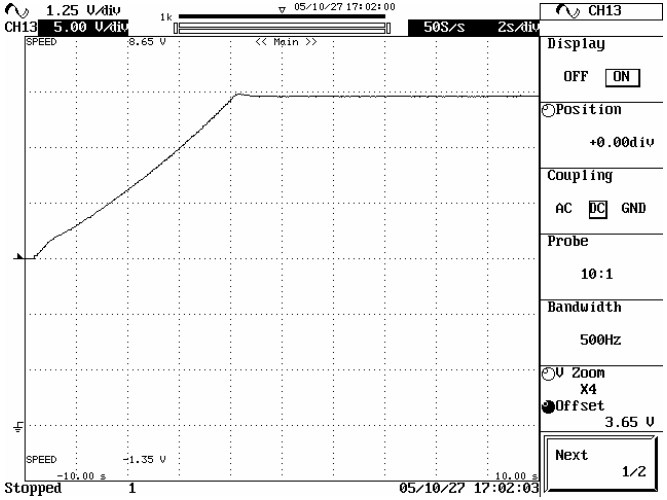
30Hz

2048 pulse encoder



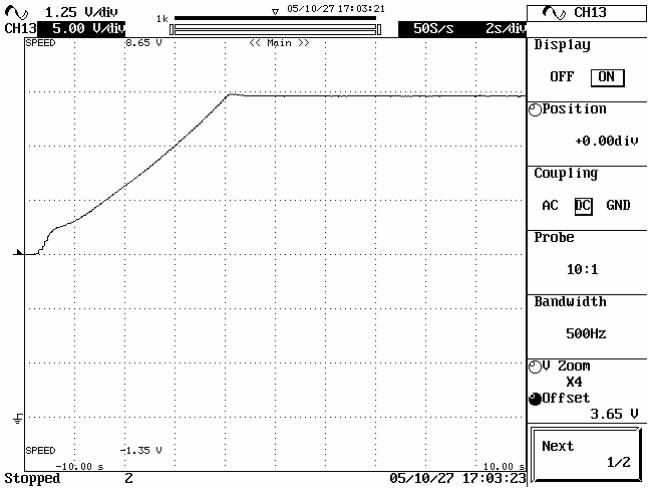
30Hz

16 pulse encoder



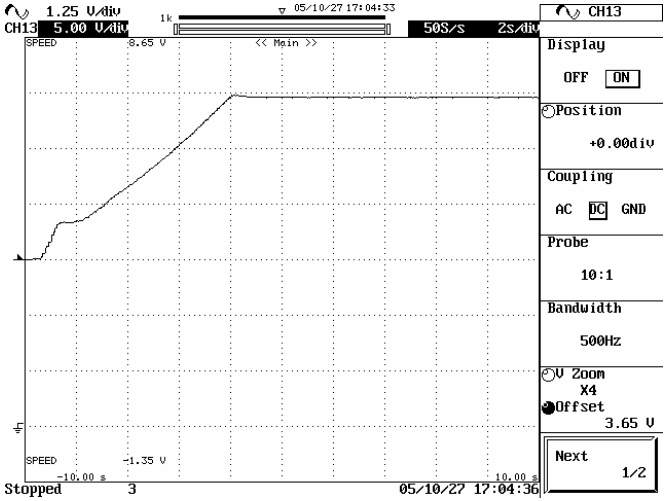
30Hz

8 pulse encoder



30Hz

4 pulse encoder



Rotor Speed

Experimental Results 3-hp IM FOC with Low-Count Encoder FOC Performance Under 12 N·m Load at 30Hz

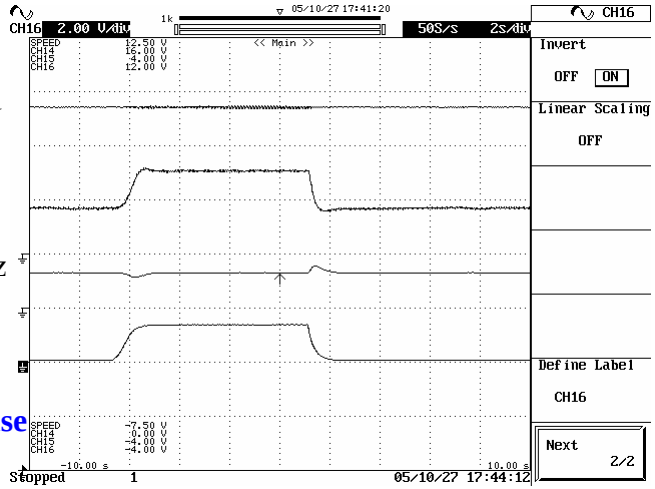
Id=0.2pu

Iq

wr=30Hz

Load

2048 pulse encoder



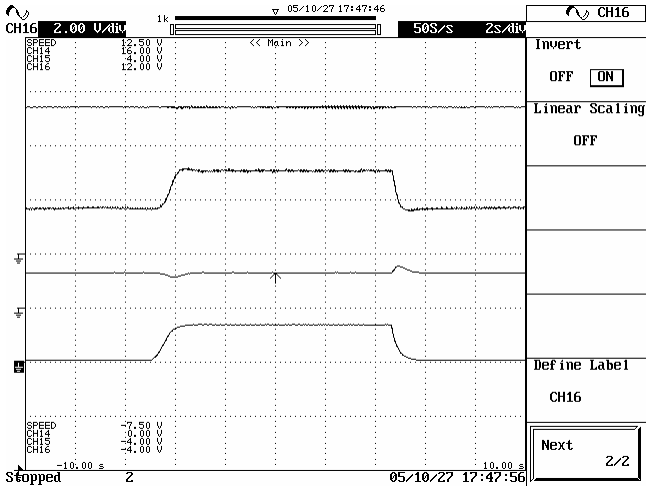
Id=0.2pu

Iq

wr=30Hz

Load

16 pulse encoder



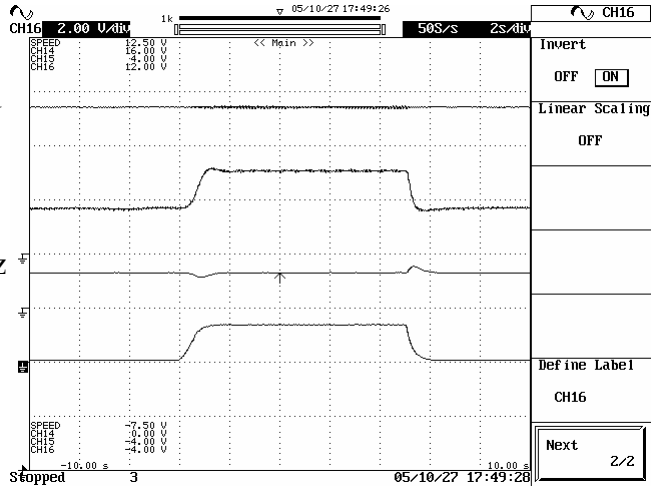
Id=0.2pu

Iq

wr=30Hz

Load

8 pulse encoder



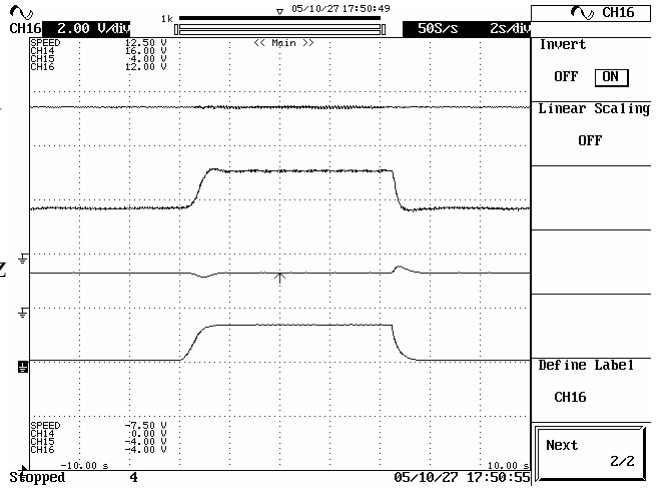
Id=0.2pu

Iq

wr=30Hz

Load

4 pulse encoder



Experimental Results 3-hp IM FOC with Low-Count Encoder FOC Performance Under 4.8 N·m Load at 3.3 Hz

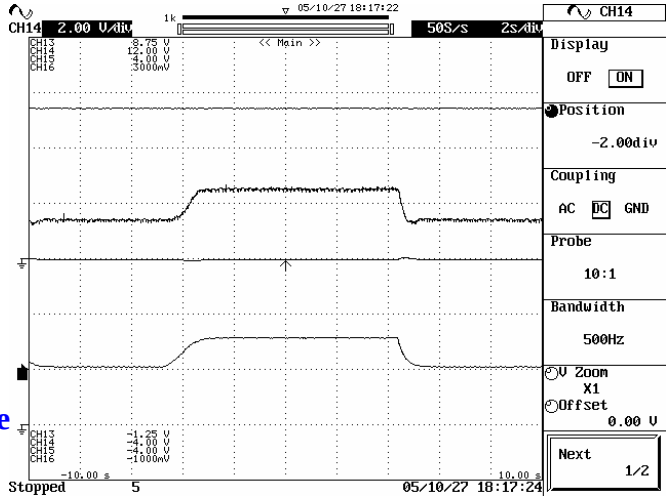
Id=0.2pu

Iq

wr=3.3Hz

Load

2048 pulse encoder



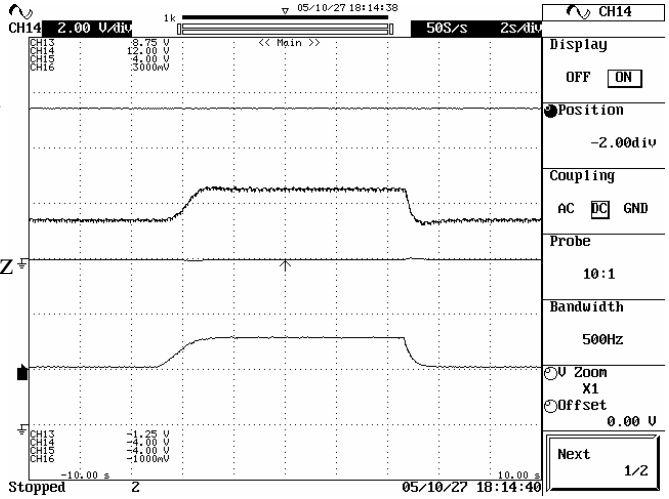
Id=0.2pu

Iq

wr=3.3Hz

Load

16 pulse encoder



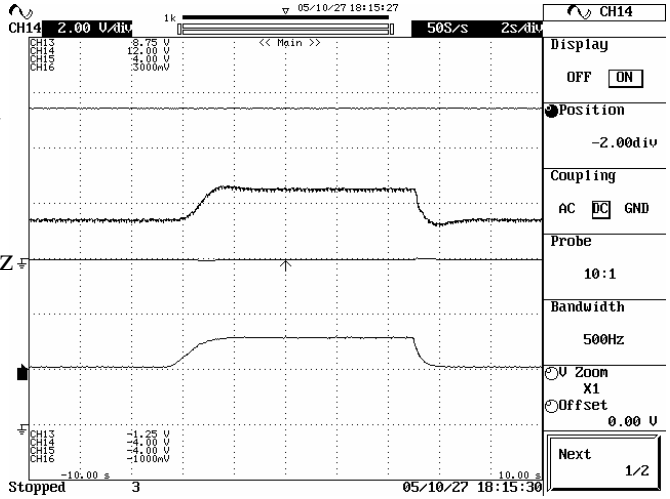
Id=0.2pu

Iq

wr=3.3Hz

Load

8 pulse encoder



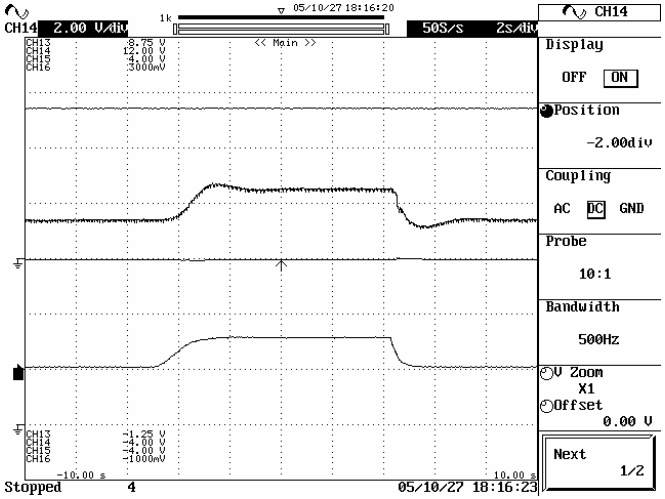
Id=0.2pu

Iq

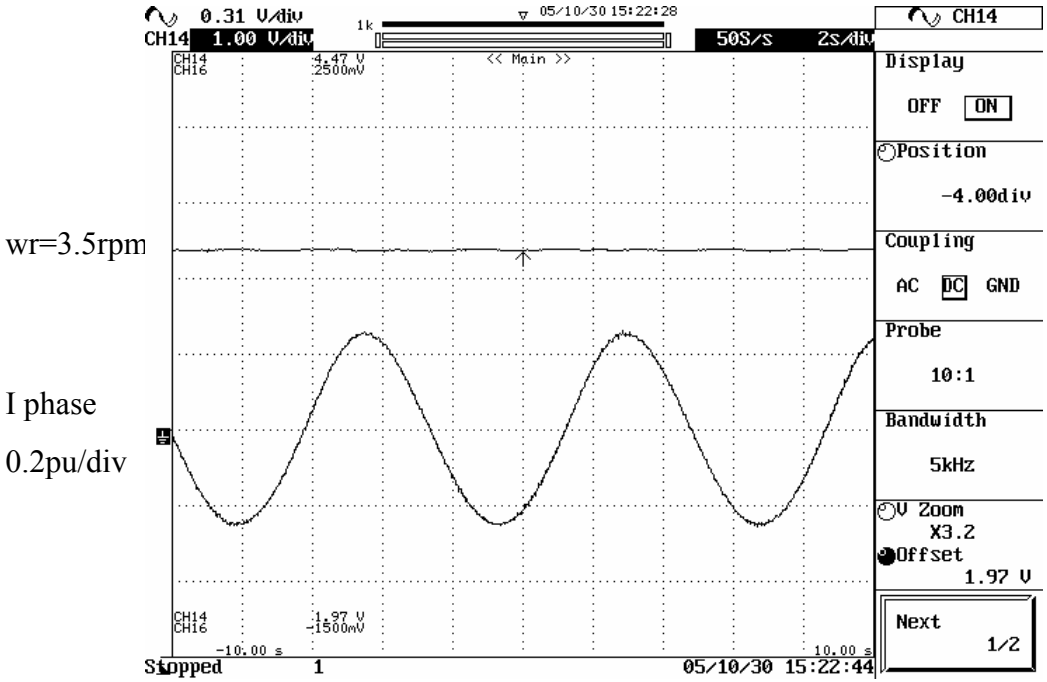
wr=3.3Hz

Load

4 pulse encoder



Experimental Results 3-hp IM FOC with 32-Pulse Encoder FOC Performance at Very Low Speed



Line Current and Rotor Speed

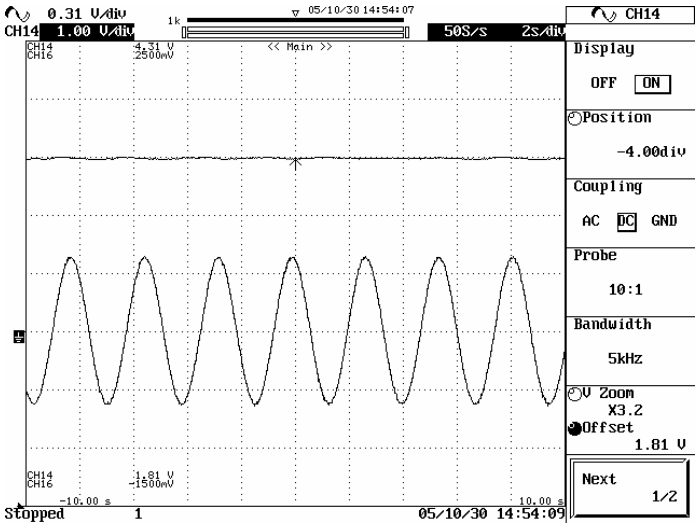
(**32** pulse encoder / 20kHz switching freq.)

Experimental Results 3-hp IM FOC with 16-Pulse Encoder FOC Performance at Very Low Speed

wr=10 rpm

I phase

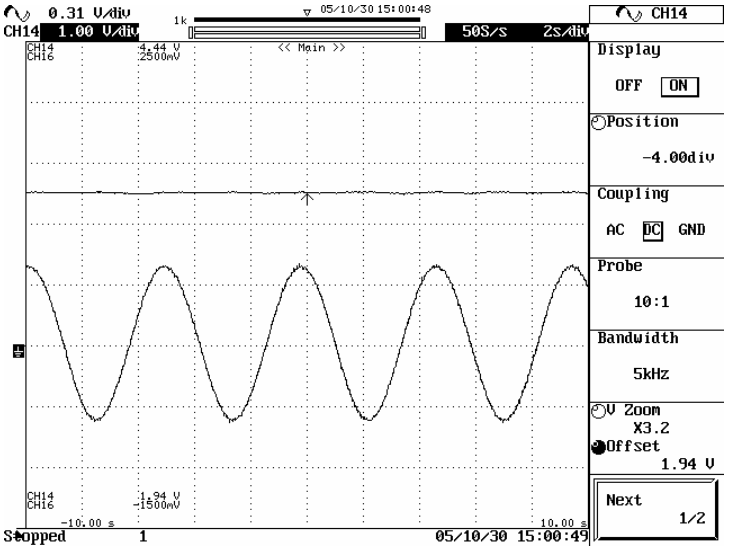
0.2pu/div



wr=5 rpm

I phase

0.2pu/div



Line Current and Rotor Speed

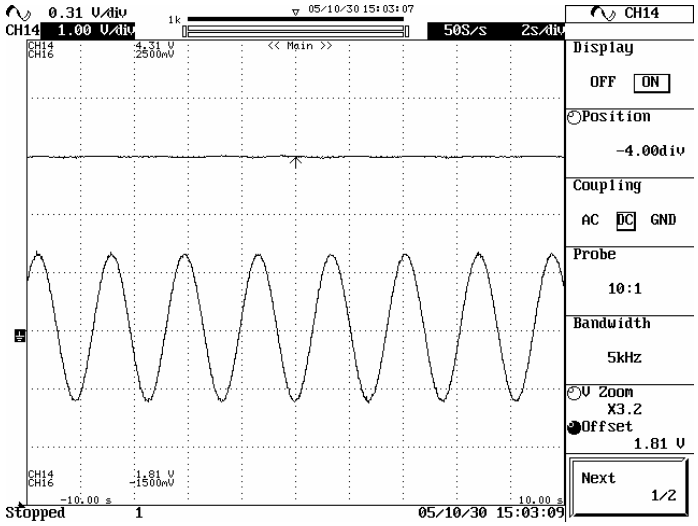
(**16** pulse encoder / 20kHz switching freq.)

Experimental Results 3-hp IM FOC with 8-Pulse Encoder FOC Performance at Very Low Speed

wr=10 rpm

I phase

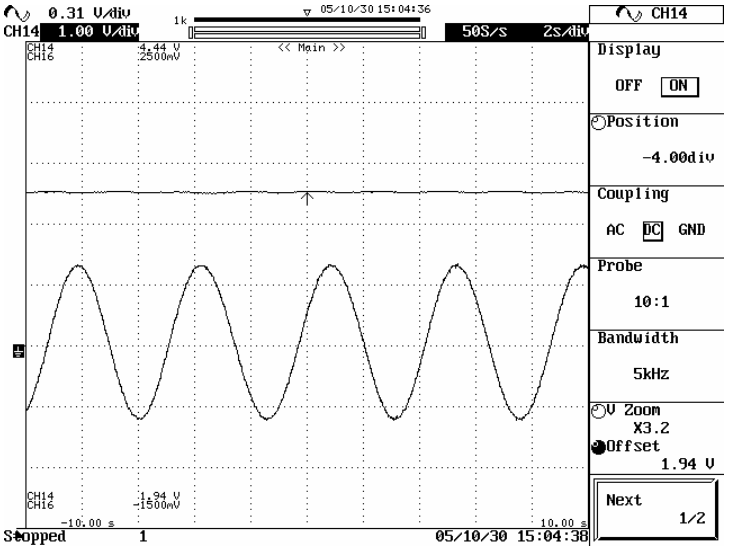
0.2pu/div



wr=5 rpm

I phase

0.2pu/div



Line Current and Rotor Speed

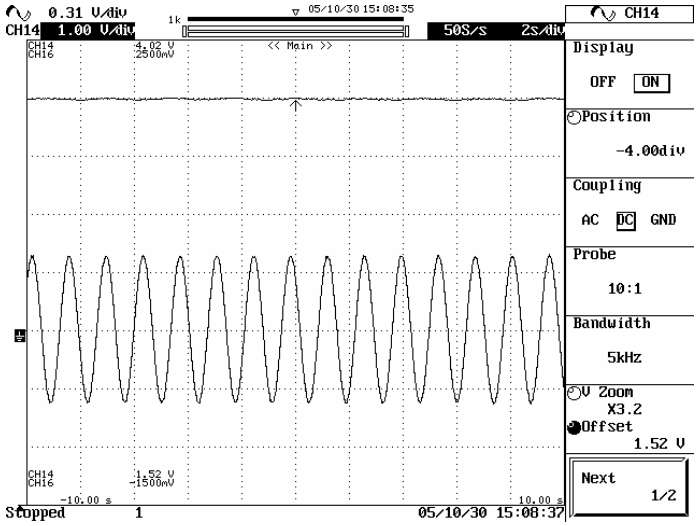
(**8** pulse encoder / 20kHz switching freq.)

Experimental Results 3-hp IM FOC with 4-Pulse Encoder FOC Performance at Very Low Speed

wr=20 rpm

I phase

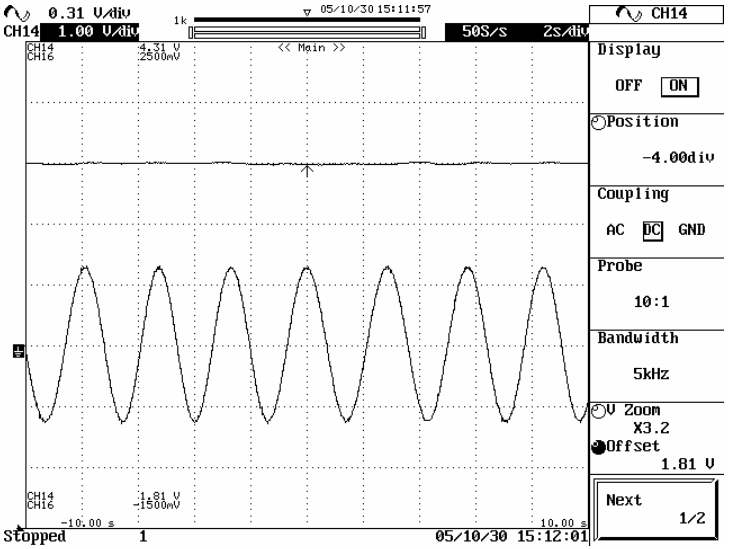
0.2pu/div



wr=10 rpm

I phase

0.2pu/div



Line Current and Rotor Speed

(**4** pulse encoder / 20kHz switching freq.)

Conclusions

- In this work, the experimental results of TMS320F28xx based FOC of IM show that it is possible to extend the low speed range down to one- digit speed values using low count encoders (4,8,16..etc) with acceptable precision and FOC performance.
- The successful low-count encoder experimental results encourage the applications of cheap hall-effect sensors in FOC based IM drive technology safely.

FOC of IM at Very Low Speed Using Low Count Encoders

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