Lab 4: Mechanical sensor failure and

sensorless control of PMSM

Connor Ricotta

400199761

# Introduction:

This lab serves to introduce various causes of sensor failure while controlling motors. First, we will observe how the motor will react under various failure states, then implement methods to detect these variations, and finally how to control properly when a sensor has entered these failure states.

# Results:

## PLL Tuning – 30Hz:

The following parameters were used to achieve a 30Hz response with a phase margin larger than 45 degrees:

A = 6

KPLL = 760

A diagram of a function

Description automatically generated

A diagram of a number of power

Description automatically generated with medium confidenceA graph with a line drawn on it

Description automatically generated

A graph with a red line

Description automatically generated

While the control strategy in thios example has exelent efficiency, observing the torque response and error metrics shows how poor this configuration was. After the step response the system has several large oscillations before slowly ramping back up to the desired torque. However, despite this the measure I d/q measured is folowing the reference extremly well.

## PLL Tuning – 300Hz:

The following parameters were used to achieve a 30Hz response with a phase margin larger than 45 degrees:

A = 6

KPLL = 760

A diagram of a function

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A graph with a black line

Description automatically generated

A graph with a line drawn on it

Description automatically generated

A black curve on a white grid

Description automatically generated

A diagram of a machine

Description automatically generated with medium confidence

A graph with a red line

Description automatically generated

After tuning for 300Hz, the system response improves greatly improved. The torque response has a much smaller dip and efficiency has greatly improved. The tracking error is greatly reduced as well despite having a ripple of 1%.

## 5% gain difference

A graph with a line

Description automatically generated

A diagram of a graph

Description automatically generated with medium confidence

A graph with a red line

Description automatically generated

A red and orange line graph

Description automatically generated

Applying the 5% gain difference had very little effect on the system. The efficiencies and ripple stayed the same, however the tracking error grew slightly. This is likely due to the increased oscillations in the response.

## 10% offset:

A graph with a line

Description automatically generated

A graph of a graph showing a red line

Description automatically generated with medium confidence

A graph with a red line

Description automatically generated

A graph showing a curve

Description automatically generated

A diagram of a motor efficiency

Description automatically generated

The offset applied to the cos signal sees some significant error in the model. While the efficiency is hardly changed, the tracking error has seen even more jumps. Looking at the response above, the oscillations have increased quite a bit. Observing the sin and cos output, there is a clear difference between the 2. This results in an extremely noisy idq as well as pll error.

Supply failure:

A graph with a line drawn on it

Description automatically generated

A graph with numbers and lines

Description automatically generated

Applying a supply failure results in the resolver no longer taking measurements, the system instead needs to move to a position prediction model. The sensor less control has an extreme response, and it immediately begins oscillating similar to how it does in the 30Hz example, however, does not begin converging on the desired torque. This is likely due to poor measurements and no longer accurately reporting correct motor commands.

## Error detection:

The sum of the sign and cos parts squared is meant to equal 1. In the event one of these previous errors occurs, the bellow function can be used to detect this error by checking if the sum of parts is less than some threshold. This threshold is there to allow for tuning depending on the exact models parameters. This will allow for some error to occur, as seen before with the gain applied, it caused very little error in the model, meaning some difference between the 2 can be tolerated before it begins to cause problems.

A black screen with white text

Description automatically generated

## Sensorless control: b=2 offset = 0

A graph with a line

Description automatically generated

A graph with lines and numbers

Description automatically generated

A graph with a red line

Description automatically generated

A graph with a line

Description automatically generated

A diagram of a motor efficiency

Description automatically generated

As seen in the previous test, the system responds very poorly when placed under fault / sensorless control. When the torque reference is altered, it immediately hits the desired torque, the proceeds to wildly oscillate before converging on zero. This is likely due to the tuning and calculation of the estimate being off, as the largest position estimate error is seen right as the reference switches, and decreases as it begins to converge.

## Sensorless control: b=2 offset = 180

A screen shot of a graph

Description automatically generated

A graph with a line graph

Description automatically generated

A graph with a red line

Description automatically generated

A diagram of a motor efficiency

Description automatically generated

After applying a +180 degree offset to the initial angle, the system response has hardly changed in terms of accuracy. However, the system has been “flipped”. Rather than spiking towards the reference, it drops to the inverse of that request.

## Sensorless control: b=2 offset = -180

A graph with a line

Description automatically generated

A screenshot of a computer

Description automatically generated

## Sensorless control: b=2 offset = 90

A graph with a line

Description automatically generated

A screenshot of a computer program

Description automatically generated

After changing the offset to -180, the system response has been dampened to the point where it has almost no response and still converges to zero. The response when changed to 90 is almost identical but slightly more dampened.

## Sensorless control: b=0.5 offset = 0

A graph with a line graph

Description automatically generated

A graph with a red line

Description automatically generated

A screenshot of a computer

Description automatically generated

A graph with a line

Description automatically generated

After changing the value of b, the system once again has some form of response. Initially, the torque follows the desired value perfectly. After the step change it continues this but immediately begins heavily oscillating as seen previously, before converging on zero once again. After observing the pll error it is clear that this is where the issue lies, having zero error until the time of the stepo change, where the system is no longer able to properly predict the motor values. This results in large amounts of error before converging on -2, corresponding to the motor delivering no torque.

## Sensorless control: b=0.5 offset = -180

A graph with a line

Description automatically generated

A diagram of a machine

Description automatically generated with medium confidence

Once again, changing the offset to the extremes results in the motor not being able to respond properly. After the step change is introduced there is almost no movement before again converging to zero with some oscillation.

# Conclusion:

This lab showed the importance of properly monitoring your motor and how to handle faults as they occur. As seen, sensor less control is extremely inaccurate and is unable to accurately represent the motor’s current condition. As seen with the PLL error, this method is not able to provide good feedback resulting in the motor being unable to provide any meaningful torque. Either a new method should be used in the event of a fault, or redundant sensors should be in place.

As for fault detection, the tuning was shown to be crucial. Some error in feedback is expected due to sensor error or motor conditions changing. However, modern control methods have shown to be resilient to some error, without causing large errors in output. Tuning for this will reduce number of false errors, and lengthen the life of your motor due to removing the need to replace as early.