Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2015-16 (3.0 hours)

EEE6201 Advanced Control of Electric Drives

Answer **FOUR** questions. **No marks will be awarded for solutions to a fifth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. **a.** A 10 poles servo motor is used in a positioning application requiring a precision of $\pm 1°$ (mechanical). What is the minimum resolution required for suitable absolute encoder (in bits)? **(4)**

b.

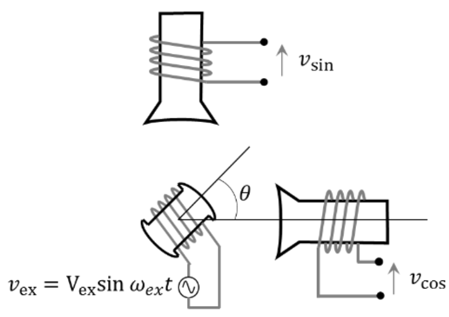

Figure 1.a

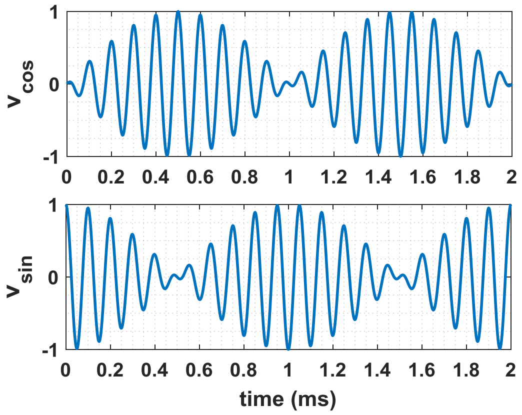

Figure 1.b

Figure 1.a illustrates the general principle of operation of a resolver. Figure 1.b shows the measured signals at the $v_{\cos}$, $v_{\sin}$ terminals. For the case illustrated in Figure 1.b, sketch the angle θ in the interval $t = [0, 2ms]$ and calculate the speed in *rpm*. **(4)**

c.

Figure 2 illustrates a block diagram of an algorithm suitable for tracking speed and angle from the resolver signals of Figure 1.b. Write an expression for signals ***(1), (2), (3), (4), (5), (6)*** and ***(7)*** as identified in Figure 2.

(8)

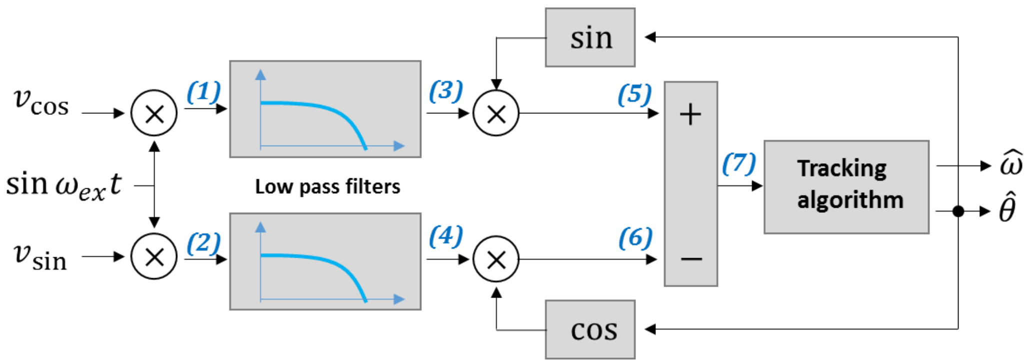

Figure 2

You might want to use the following trigonometric identities:

$$\sin^2 \alpha = \frac{1}{2}(1 - \cos 2\alpha)$$

$$\sin(\alpha + \beta) = \sin \alpha \cos \beta + \cos \alpha \sin \beta$$

$$\sin(\alpha - \beta) = \sin \alpha \cos \beta - \cos \alpha \sin \beta$$

d. With the help of a block diagram, describe a suitable tracking algorithm to be used in the block diagram of Figure 2 and write an expression for the transfer function between the input ***(7)*** and the two outputs $\hat{\omega}$ and $\hat{\theta}$. **(4)**

2. A 4-poles Permanent Magnet Synchronous Motor (PMSM) has the following parameters in nominal conditions:

Stator resistance: $R_s = 0.1\Omega$.

Synchronous inductance: $L_d = L_q = 1\ mH$.

Rotor flux: $\psi_m = 0.1\ Vs$.

The motor is driving a mechanical load with a combined motor and load inertia $J = 0.1\ kg \cdot m^2$.

a. Sketch a block diagram of a suitable current controller in the synchronous reference frame including ideal decoupling compensation and explain the function of the decoupling compensation. **(4)**

b. Design the PI current controllers resulting in a first order closed loop transfer function with a bandwidth $f_{cc} = 1\ kHz$. **(4)**

c. Sketch the frequency domain magnitude response of:

i. the closed loop current control. **(2)**

ii. the open loop speed control assuming a closed loop bandwidth for the speed loop $\omega_{sc} = 314.16\ \frac{rad}{s}$ and $\omega_{PI}^{speed} \ll \omega_{sc}$. **(4)**

d. Select the proportional and integral gains $K_{i,s}$ and $K_{p,s}$ of the speed controller assuming the breakdown frequency of the PI speed controller is $\omega_{PI}^{speed} = \frac{1}{10}\omega_{sc}$. **(6)**

3. A Permanent Magnet Synchronous Motor (PMSM) is rotating in open circuit conditions at a mechanical speed $\omega_m = 15000\ rpm$ (revolutions per minute).

In these conditions, the measured line to line voltage v_{ab} is illustrated in Figure 3.

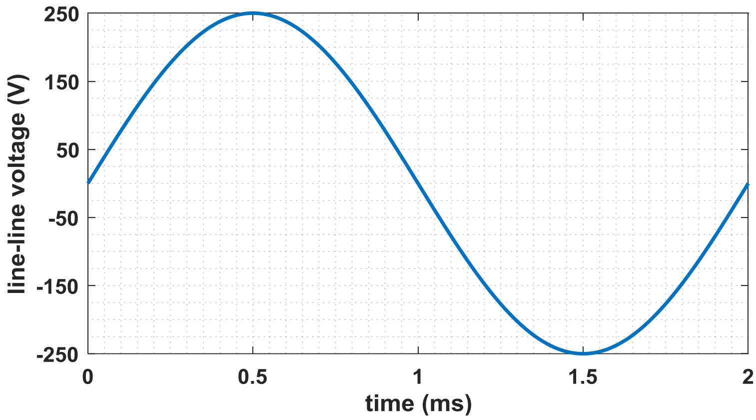

Figure 3

The motor is subsequently operated in short circuit conditions at the same speed. In these conditions a breaking torque of 3 $[Nm]$ and the following currents are measured:

$$\begin{aligned} i_d &= -100\ A \\ i_q &= -10\ \ A \end{aligned}$$

Assuming that the machine has negligible iron losses, calculate:

a. the number of magnetic poles the machine has **(2)**

b. the magnet flux ψ_m; stator resistance R; d- and q-axis inductances L_d, L_q. **(8)**

c. Assuming that the motor is then operated under maximum efficiency, calculate:

i. the maximum power it can produce at 3000 *rpm* with stator currents limited to $20A$ **(8)**

ii. the efficiency at 3000 *rpm*. **(2)**

4. An 8-poles Permanent Magnet Synchronous Machine (PMSM) has negligible phase resistance, rotor magnet flux $\psi_m = 0.09\,Vs$ and inductances $L_d = 500\mu H, L_q = 1\,mH$.

For this motor, the normalised output torque is shown in Figure 4 as a function of the stator current angle.

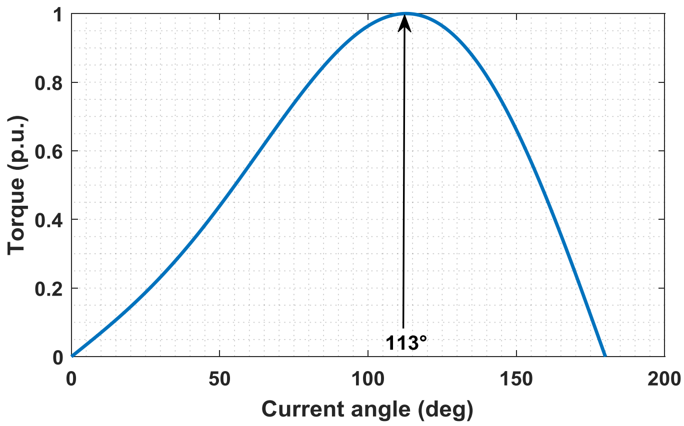

Figure 4

The motor is driven by an inverter with peak current limited to $100A$. The inverter is operated with sine-triangle PWM and is supplied by a dc-link voltage $V_{dc} = 400\,V$. For this drive, calculate:

a. The maximum output torque that the motor drive can produce **(2)**

b. The maximum speed in rpm at which maximum torque can be produced **(5)**

c. The absolute maximum speed in rpm that can be reached by the drive **(5)**

d. The maximum torque that can be produced at $6000\,rpm$. **(8)**

5. A 4-poles Permanent Magnet Synchronous Machine (PMSM) has the following parameters:

$\psi_m = 0.1\, Vs$

$L_d = 500\mu H, L_q = 1\, mH.$

The motor is driven using Field Oriented control with a position sensorless algorithm based on the injection of a $12V$, $500Hz$ voltage signal into the estimated d −axis.

a. With the help of a block diagram, describe a suitable algorithm for the detection of the rotor angular position, based on measurement of the stator currents. **(6)**

b. The motor is operated at zero speed and zero torque demand, with an estimated rotor angle $\hat{\theta} = 0$. Figure 5 shows the measured currents $\hat{i_d}, \hat{i_q}$ in the estimated synchronous reference frame.

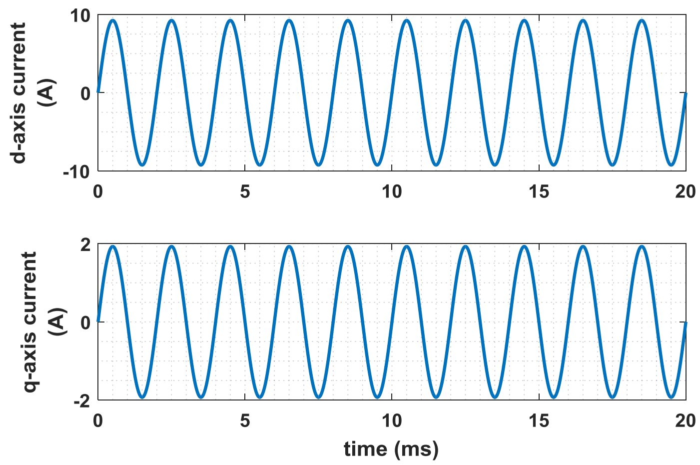

Figure 5

i. With the help of a vector diagram show the relationship between the actual and estimated synchronous reference frames **(2)**

ii. Provide an expression for the injected voltages in the real and estimated reference frames **(3)**

iii. Provide an expression for the high-frequency components of stator currents in the real and estimated reference frames **(6)**

iv. Calculate the real rotor position. **(3)**

6. A three-phase star-connected 4-poles induction motor (IM) has the following parameters referred to the stator:

Stator resistance: $R_s = 0.2\Omega$.

Rotor resistance: $R_r = 0.2\Omega$.

Stator inductance: $L_s = 25mH$.

Rotor inductance: $L_r = 30mH$.

Mutual inductance: $L_m = 20mH$.

The motor is in steady-state conditions and is operated under indirect Field Oriented Control (FOC) at $3000\,[rpm]$. The measured stator currents in the synchronous reference frame are:

$i_d^s = 10\,A$

$i_q^s = 90\,A$

Calculate:

a. The rotor flux linkages ψ_d^r, ψ_q^r. **(2)**

b. The rotor currents i_d^r, i_q^r. **(2)**

c. The stator flux linkages ψ_d^s, ψ_q^s. **(2)**

d. With the help of a block diagram, explain the operation of the IM synchronous current control using the indirect FOC. **(6)**

e. Calculate the slip frequency ω_{slip}. **(4)**

f. Calculate the stator voltages v_d^s, v_q^s. **(4)**

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