Duration: 2h00.

Notes:
*** Write your name on every exam sheet you submit**
*** Closed book exam**
*** The use of any calculator with graphic support is prohibited**

1. [2] In an electric motor, the generation of torque can be related to two different processes: the Lorenz force and the Reluctance force. For each of these two processes, name and describe two types of motors that utilize them. Do not forget to mention the type of electrical power supply required for each motor.

2. [1] Some BLDC motors, equipped with a low-resolution rotor position detector (typically 3 Hall sensors) and an integrated driver, are used for driving ventilation fans as an alternative to DC brushed permanent magnet motors.
   a) What are the advantages of these BLDC motors, when compared to DC brushed permanent magnet motors?
   b) Identify two possible solutions that can be employed to adjust the speed of an BLDC motor that drives a fan.

3. [1] For some electric motors, the use of *star-delta* starters are sometimes mentioned.
   a) Indicate which motors can use this type of starter and identify what electromechanical components are employed.
   b) Draw a typical torque-speed curve for a motor using this type of *star-delta* starter.

4. [1] When using stepper motors, it is common to refer to "phases, poles, step angle". Based on the scheme (incomplete) presented on Figure 1 that refers to a particular type of stepper motor, identify:
   a) Type of motor and the step angle, knowing that the number of steps per turn is 24.
   b) Number of phases and number of poles per phase.

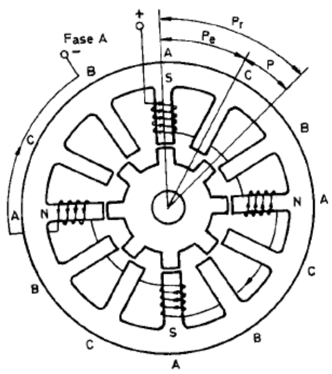

Figure 1

5. [1] Soft starters are known to offer a start mode that utilizes a voltage ramp complemented by an initial voltage pulse, often referred to as the *kick start* mode. Explain the benefits of this feature. Additionally, what other start modes are available with soft starters?

6. [1] When considering electric motors for battery electric vehicles(BEV), one potential option is the use of axial flux permanent magnet synchronous motors (PMSM), like those produced by YASA (Figure 2).
   What are the primary benefits of these motors in comparison to the conventional radial flux PMSM

Figure 2 - Yasa motor

7. [2] The main functions of switch gear devices include control, protection and isolation of electrical installations and equipment. Consider the electrical circuit presented in Figure 3, used for on/off control of an induction motor. Identify and classify the components A, B, C, D and E.

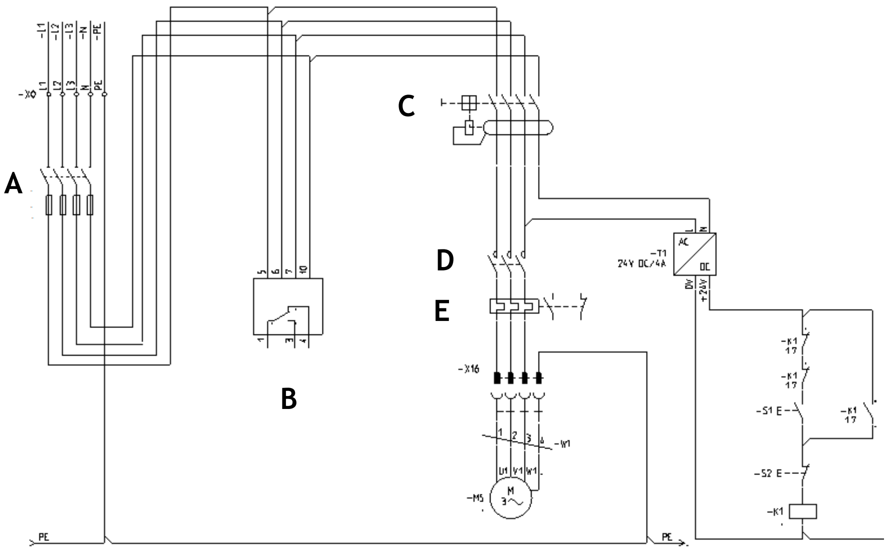

Figure 3

8. [2] Miniature circuit breakers (MCB) can present different trip curves, such as type B (suitable for residential applications), type K (suitable for motors and transformers), and type Z (suitable for semiconductors). Why there is an interest in having different trip curves? Sketch the trip curve for type B, type K and type Z in the same graphic. When selecting a MCB, name four other aspects that need to be considered, apart from the trip curve.

9. [1] When sizing an electrical cable for powering an induction motor, apart from the cable short circuit current rating, what are the two other aspects to consider?

10. [5.5] The Figure 4, below, represents a similar case as one used in the lab classes to illustrate the application of induction motors to actuate the two rotation movements of a turntable: (1) the orientation of the table, (2) the rotation of the rollers. Given the specificity of this type of application for electric motors, answer the following questions.

    a) Please indicate three reasons that justify the use of three-phase induction motors with VFD (Variable Frequency Drive) for this type of applications.
    b) Based on the data available on Figure 4, calculate the static power and the load acceleration power required by this load for the <u>orientation</u> movement (1).
    c) Verify if the <u>0,55 kW motor</u>, from the Table 1, below, run by a VFD <u>at 70 Hz</u>, can be used to drive the table orientation movement (1). Consider that a gearbox is used to convert the motor speed at 70Hz to the required table rotation speed.
    d) Represent the characteristics curves (speed, torque) and (frequency, voltage) corresponding to the base (50Hz) and maximum (70Hz) frequencies. Can this type of solution ensure the table will run at the specified speed?
    e) Estimate the value of the electric power consumed by the motor, when rotating at constant speed with one container.

- $m_{containers} = 350\ kg$
- $m_{rotating\ platform} = 113\ kg$
- $\phi_{table} = 1\ \mathrm{m}$
- $\phi_{table\ supporting\ bearings} = 0{,}5\ \mathrm{m}$
- $\mu_{friction\ coefficient\ of\ supp.bearings} = 0{,}01$

- $J_{total\ rotating\ weigths}^{table\ rotation\ axis} = 33{,}6\ kgm^2$
- $n_{table} = 28\ rpm$
- $t_{acceleration} = 1{,}0\ s$
- $\eta_{gearbox} = 0{,}71$

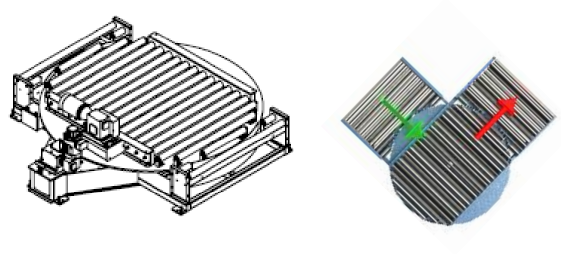

Figure 4

Duration: 2h00.

Table 1: The values correspond to a 50 Hz specification; ZBE corresponds to a motor with an incorporated electromechanical brake.

4-pole Z.E. motors 100% CDF (IE2)

Type	P_N [kW]	n_N [rpm]	M_N [Nm]	I_N 400 V [A]	$\cos\varphi_N$	IE - 2 $\eta_{1/2}$ %	$\eta_{3/4}$ %	4) $\eta_{4/4}$ %	I_A/I_N	M_A/M_N	M_K/M_N	J_{Mot} [kgm² x 10^{-3}] ZNE	ZBE	Z_0 [1/h] 1)	2)	Brake Type	[Nm] M_{BStd}	Weight [kg] 3) ZNE	ZBE
Z.E 63 B4	0,18	1385	1,2	0,6	0,64	66,5	71,2	72,1	4,0	2,8	2,8	0,55	0,61	13000	13000	B003	2,5	7,8	10,5
Z.E 71 A4	0,25	1390	1,7	0,8	0,63	69,5	74,0	74,9	4,0	3,0	3,0	0,65	0,71	10000	12000	B007	3,4	8,5	11,2
Z.E 80 A4	0,55	1420	3,7	1,5	0,68	78,0	78,3	78,1	5,0	3,0	3,0	1,43	1,49	7800	11200	B007	7,6	12,2	15,6
Z.E 80 B4	0,75	1425	5	2	0,66	79,3	82,2	79,6	4,9	2,8	3,0	2,06	2,19	9400	13500	B020	10	15,1	19,5
Z.E 90 A4	1,1	1445	7,3	2,7	0,69	79,8	82,3	81,4	5,7	2,3	2,8	2,47	2,60	9400	13500	B020	16	16,0	20,4
Z.E 90 B4	1,5	1435	10	3,3	0,77	82,1	83,4	82,8	6,2	2,7	3,2	4,60	4,73	5000	7200	B020	20	20,7	26,3
Z.E 100 A4	2,2	1430	14,6	4,7	0,79	83,8	84,9	84,3	6,1	2,3	3,0	5,75	6,21	5400	7800	B050	33	24,5	33,6
Z.E 100 B4	3	1445	19,8	6,6	0,77	83,6	86,4	85,5	5,6	2,0	2,8	7,06	7,52	5300	7600	B050	39	23,2	32,3

▭ Only for operation with an inverter

1) Operation with brake rectifier without high-speed excitation
2) Operation with brake rectifier with high-speed excitation
3) Weight for B14 model
4) The nominal efficiencies as per efficiency class IE2 in accordance with IEC 60034-30 are specified

11. [2.5] Table 2 below, represents an example of information provided by manufacturers of Permanent Magnet (PM) servomotors, in order to help users selecting drivers for a given PM servomotor.

    a) Selecting a specific combination of motor and drive from Table 2, characterize as best as possible the dynamic and thermal zones of the servomotor.
    b) What is the meaning of effective (or rms) and maximum working points when sizing a PM servomotor for a given application?
    c) Another sizing parameter that must be considered is the inertia ratio limitations. In case the chosen motor does not satisfy this criterion, indicate two possible alternative solutions to overcome this problem.

Table 2: Example of data available for servomotors and respective drives

NON-VENTILATED MOTORS	Stall torque	Peak torque	Rated speed	Stall current	Peak current	Power	torque constant	acceleration time	inductance per phase	resistance per phase	Inertia ••	mass	Peak torque (Nm) for 0.5 s							
	Mo	Mp	n_N	Io	Imax	Pcal	Kt	tac	L	R	J	P	1.08	1.15	1.25	1.35	2.50	2.75	3.100	3.150
	N·m	N·m	rpm	Arms	Arms	kW	Nm/Arms	ms	mH	Ω	kg·cm²	kg	N·m	N·m	N·m	N·m	N·m	N·m	N·m	N·m
FXM73.12A.☐☐.☐☐0	20.8	104	1200	4.9	24.5	2.6	4.2	7.4	46	3.05	61	29		63.0	**104.0**	-	-	-	-	-
FXM73.20A.☐☐.☐☐0	20.8	104	2000	8.2	41.0	4.4	2.5	12.3	17	1.10	61	29			62.5	87.5	**104.0**	-	-	-
FXM73.30A.☐☐.☐☐0	20.8	104	3000	12.3	61.5	6.5	1.7	18.4	7.4	0.49	61	29			42.5	59.5	85.0	**104.0**	-	-
FXM73.40A.☐☐.☐☐0	20.8	104	4000	16.5	82.5	8.7	1.3	24.6	4.2	0.27	61	29				45.5	65.0	97.5	**104.0**	-

Notes: $J^{motor}_{linear\ load} = \frac{m}{h} \cdot \left(\frac{v}{w}\right)^2$; $T^{f2>fbase}_{max} = T^{fbase}_{max} \cdot \left(\frac{fbase}{f2}\right)^2$; $\sum T_{ext} = J_{total} \cdot a$;

$T^{fmax}_{max\ load} < 130\% \ \frac{P^{vfd}_N}{\omega_{max}}$