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] Compare the working principle of a brushless DC (BLDC) motor with a brushed DC. Explain how a BLDC motor differs from a brushed DC motor in terms of construction and operation. What are the main advantages and disadvantages of using BLDC motors in automobile applications?

2. [2] Three-Phase Induction Motors vs. Three-Phase Synchronous Motors
a) What are the main common characteristics shared by three-phase induction motors and three-phase synchronous motors?
b) Describe the key differences between three-phase induction motors and three-phase synchronous motors in terms of their construction, operation, and typical applications.

3. [1] One of the key parameters used to characterize a three-phase induction motor is its efficiency class (IE), that is determined according to the IEC 60034-30 standard.
What does this parameter indicate and what is the significance of using a IE4 instead of a IE2 motor in a given application?

4. [2] Consider the torque-speed curve of a stepper motor (Kollmorgen MH172), a hybrid stepper motor with 2 phases and 200 steps per revolution, as presented in Figure 1.
   a) Given that this motor can be configured for either parallel or series connection, which curve (A or B) corresponds to the series configuration? Justify your answer.
   b) How many wires would you expect this motor to have?
   c) For the motor configured in series, indicate the start/stop region, on the figure. This is the zone where the motor can start, stop, or change directions in synchronism without the need for acceleration or deceleration.

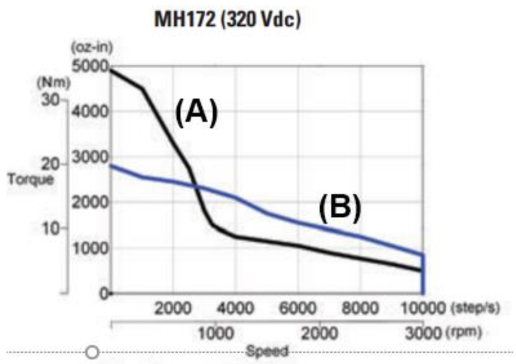


Figure 1

5. [1] WEG provides a motor, W23 Sync+, that combines synchronous reluctance with permanent magnets inside the rotor.
   a) How does the combination of synchronous reluctance and permanent magnets influence the performance and efficiency of the W23 Sync+ motor?
   b) Can this motor be controlled directly from the electric grid using Direct-On-Line (DOL) starting? Justify your answer.

6. [1] In electrical circuits, various devices are used to protect against overcurrent and short circuits. Two common ones are circuit breakers and fuses. Compare them in terms of mode of operation, type of protection, and functionality they offer. Present their respective electrical symbols.

7. [2] Figure 2 presents a double three-pole contactor with a mechanical interlock.
   a) What is one possible application for this device? Draw an electric circuit that incorporates this component and includes an electric motor.
   b) What key parameters would you consider when selecting a contactor for the circuit you draw.

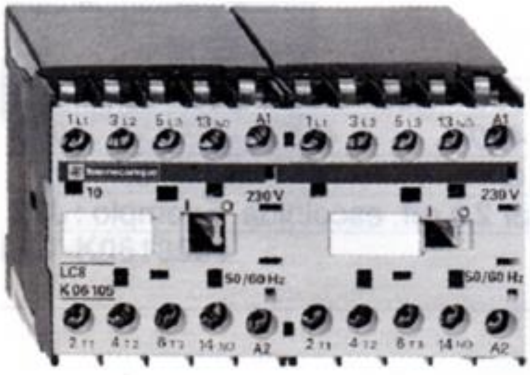


Figure 2

8. [1] What are the key functions of power meters in electrical systems, and how do they contribute to the monitoring and management these systems?

9. [5.5] Consider the operation of a lifting platform with the following operating conditions:

   - *m*_(maximum load) = 2300 kg;  *m*_(movable platform) = 400 kg; *v*_(max. Velocity ) = 0,07 m/s

   Also, consider an overall efficiency of 90% from the motor shaft to the lifting and guiding mechanism of the lifting platform.

   a) Present the steps followed and respective calculations to choose a three-phase induction motor, from the table below, that meets the requirements of this application.
   b) Check if the acceleration time is compatible with this type of motor.
   c) Represent the characteristic torque/speed curve, indicating the values corresponding to the chosen motor and the operating point for maximum load.
   d) Explain the meaning of the $Z_0$ parameter in Table 1 and how it can be used in the selection of a specific motor.

**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 4) $\eta_{1/2}$ % | $\eta_{3/4}$ % | $\eta_{4/4}$ % | $I_A/I_N$ | $M_A/M_N$ | $M_K/M_N$ | $J_{Mot}$ [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 |

(shaded) 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

Duration: 2h00.

10. [2.5] The use of variable frequency drivers (VFD) to control three-phase induction motors has numerous implications, including in the respective characteristic curves.

    a) From the user perspective, describe the main elements of a variable frequency driver and the respective functionalities. If you prefer, you can also use a representation of the main block diagrams.
    b) Consider one motor, at your choice, from table 1 and represent the characteristic curves when using a VFD to control the motor from 0 to 70 Hz.
    c) In relation to applications where the load movement leads the motor to work as a generator, a regenerative type VFD is more expensive than the more conventional dissipation through a power resistance solution?

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

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