Xi'an Jiaotong-Liverpool University

西交利物浦大學

MEC108 Introduction to Mechatronics:

Coursework 2

This is Due at: 23:59, 10 June, 2021

Assignment Regulations

- This is an individual assignment. Everyone MUST submit one soft copy of the report via the ICE before the due date.

- A coversheet can be created in your own way, but the following information MUST be included: your full name, student ID number, and email address.

- An answer sheet needs to be provided. You can organize your answer sheet in your own way. The recommended way is; (1) copy each question and, (2) put your answers below each question. You are allowed to hand write your answers, but make sure your answer sheet is neat and clear.

- You may refer to textbooks and lecture notes to discover approaches to problems, however, the assignment should be your own work.

- Where you do make use of other references, please cite them in your work. Students are reminded to refer and adhere to plagiarism policy and regulations set by XJTLU.

- Assignments may be accepted up to 5 working days after the deadline has passed; a late penalty of 5% will be applied for each working day late without an extension being granted. Submissions over 5 working days late will not be marked. Emailed submissions will NOT be accepted without exceptional circumstances.

MEC108 Coursework 2

Development of a Motor Control System for an Air-Blower Fan

(100 Marks)

Consider an air-blower fan as shown in Figure 1, which is used in many industrial applications to supply air as required. It is now proposed that the air-blower fan is driven by an induction motor, and the shaft of the air-blower fan is rotating at the output rotating speed of the motor (hereafter referred to as the shaft speed). The air supplying volume flow rate is proportional to the shaft speed:

$$Q \propto n \tag{1}$$

and the air pressure inside the blower fan is proportional to square of the shaft speed:

$$p \propto n^2 \tag{2}$$

The power consumption of the blower fan is directly proportional to the product of volume flow rate and pressure, and thus the cubic of the shaft speed:

$$P \propto Qp \propto n^3 \tag{3}$$

Consider the rated conditions of this air-blower fan are given by Q_{fan_rated} at n_{rated}, corresponding to the rated power of P_{rated}. Thus, when the blower fan is supplying any other air flow rates (usually smaller than Q_{rated}), the power consumption is

$$P_{fan} = P_{fan\_rated}\left(\frac{n_m}{n_{rated}}\right)^3 \tag{4}$$

where n_m is the actual shaft speed corresponding to one particular air flow rate (Q_{fan}).

Figure 1. The real product of the air-blower fan assembly.

Now, we have an air-blower fan whose rated power is $P_{fan\_rated} = 92\ kW$ corresponding to its rated speed of around $n_{rated} = 1800\ rpm$. Therefore, the fan power varies with its speed as:

$$P_{fan} = 92.0\left(\frac{n_m}{1800}\right)^3 \quad kW \tag{5}$$

An induction motor with the following parameters are used to drive this air-blower fan:

Number of phases: 3; Rated voltage: 575 V; Rated power: 100 kW; Number of poles: 4; Connection type: Y

The per-phase impedances in Figure 2: $R_1 = 0.102\ \Omega$, $R_2 = 0.125\ \Omega$, $X_M = 35.40\ \Omega$, $X_1 = 0.239\ \Omega$, $X_2 = 0.344\ \Omega$.

Motor losses of $P_{F\&W}$, P_{misc} and P_{core} can all be assumed to be negligible.

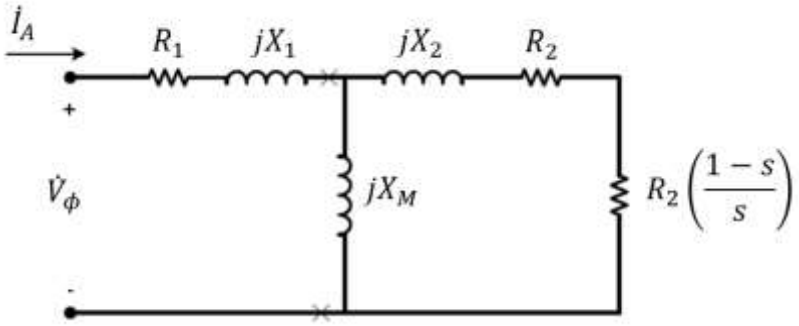


Figure 2. The induction motor per-phase equivalent circuit.

Industrial applications usually require an air-blower fan be able to supply air at a number of different flow rates as required. Thus, a speed-control system is required to vary the motor's speed, accordingly.

Now, consider the motor control system for this application, with the following specifications:

- Use the variable frequency drive (VVVF), under the mode of constant voltage-frequency ratio.
- The upper limit of frequency is 60 Hz (the rated frequency), corresponding to the motor's terminal voltage of 575 V.
- The lower limit of frequency is 24 Hz, when the motor's power factor does not fall below 0.80.
- The control system has three choices of rotational speed, corresponding to 3 choices of air supplying volume flow rate. The three choices are tabulated below.

	Actual Speed (rpm)	Power Frequency (Hz)	Load power (kW)	Input Current (A)	Slip (%)	Power factor (%)
Speed 1	710	24	5.6	17.4	1.4	81.4
Speed 2	1230	42	29.3	45.7	2.5	91.9
Speed 3	1740	60	82.5	91.4	3.6	90.6

The torque-speed characteristic curves at different frequency, together with the load characteristic curve, are shown in Figure 3 which also shows the working point at each frequency.

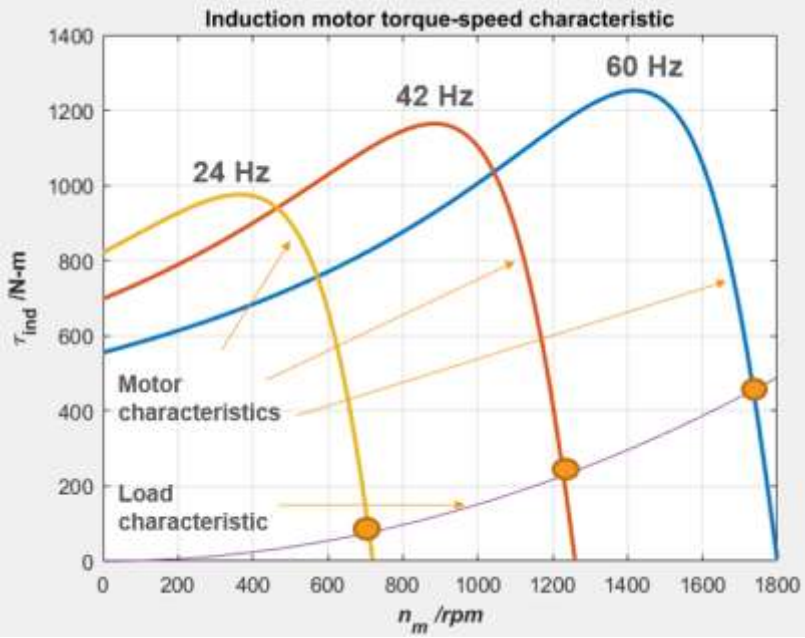
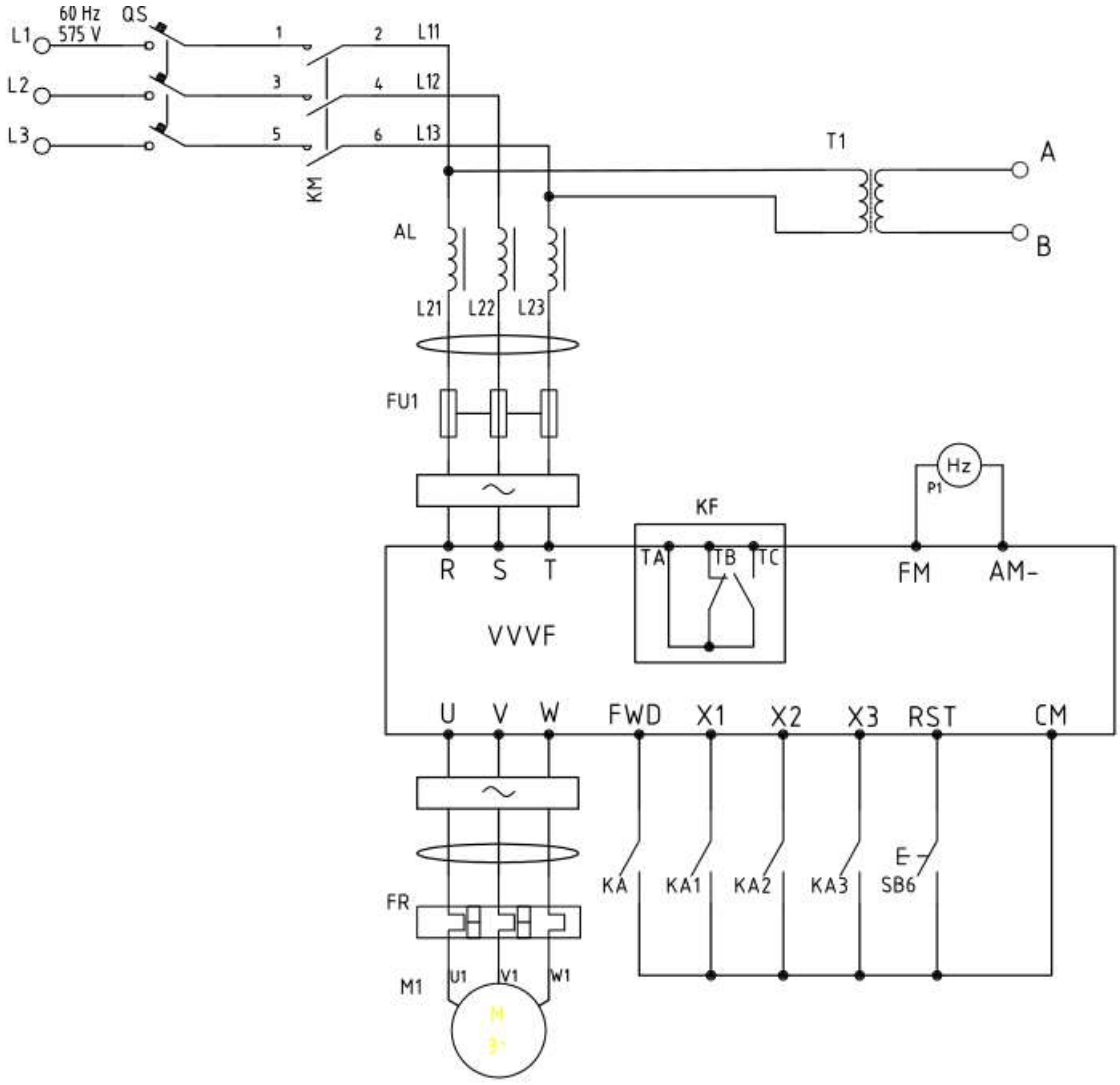
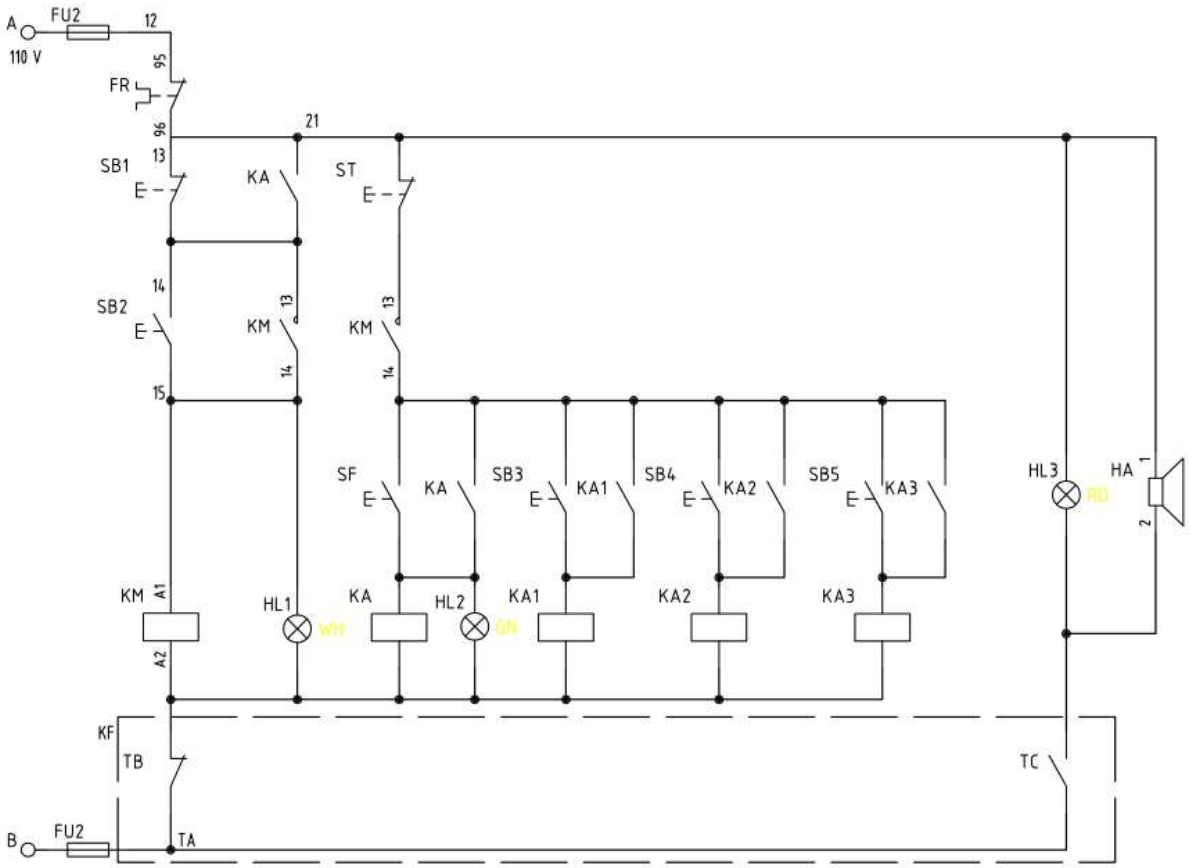


Figure 3. The motor characteristics and load characteristic as a function of speed at different frequencies. The working point at each frequency is shown.

- The electric schematic drawing of the VVVF based motor control system using traditional electromagnetic relay control circuit is shown in Figure 4.



(a) Power Circuit



(b) Control Circuit

Figure 4. The Variable Speed Motor Control System

Tasks of Course Work 2

A. Answer the follow questions for the circuit in Figure 4

- A general description of the working principle.

(16 Marks)

- What aspects are considered in the circuit design, e.g.:
  - Power supply and power line voltage:
  - Control circuit (what is your proposed voltage level for this, and why?)
  - What is your load of the electrical control system?
  - What protection mechanisms have you proposed in the whole circuit, and what are the corresponding components chosen for each protection mechanism?

(16 Marks)

- A list of all components included in your design and the function of each component in the circuit. A table (with examples, see below) can be used to list: (1) item No.; (2) Symbol name; (3) Component name; (4) Its functionality in the circuit; (5) quantity.

(8 Marks)

No.	Code	Name	Quantity
1	QS	Circuit Breaker	1
2	KM	AC Contactor	1
3	KA, KA1, KA2, KA3	Control Relay	4
…	…	…	…

B. Improving the motor control system by using Programmable Logic Controller (PLC) based control

- Describe the purpose of using a PLC based control

(5 Marks)

- Provide the sketch of the PLC based Electrical Control Circuit Schematic Diagram:
  - In your sketch, indicate different parts of the circuit, e.g. where is the power circuit and where is the control circuit (and where is this control circuit get power from?).

(20 Marks)

- Give a table detailing I/O allocation for the PLC.

(5 Marks)

- Complete LAD programming based on your I/O allocation and the above sketched control circuit. In your answer, present the LAD program. The programme should follow the convention used by B&R Automation, i.e. their products and software (Automation Studio), for details, please refer to Lab 1 and 2 notes and videos.

(20 Marks)

- Briefly describe how the LAD programme works, i.e.:

(10 Marks)

  - Does every network map with every control branch of the traditional control circuit as shown in Figure 4(b)?
  - By using PLC programme, which physical components (e.g. auxiliary contacts) originally in traditional control circuit of Figure 4(b) have been replaced with soft components (e.g. a soft contact)?

Hints: for this course work, you can refer to the following lecture notes:

Lab 1 notes, pp. 63 - 73
Topic 4 Part IV, pp. 45 – 49, pp. 66 - 71