NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF APPLIED SCIENCES

BSC HONOURS DEGREE IN APPLIED PHYSICS

DEPARTMENT OF APPLIED PHYSICS: PART IV

SPH 4206: INSTRUMENTATION CONTROL AND TECHNOLOGY

Second Semester Supplementary Examination Paper

21 August 2024

This examination paper consists of 5 pages.

Time Allowed: **3 hours**

Total Marks: **100**

Special Requirements: *None*

Examiner's Name: **Mr C Chuma**

INSTRUCTIONS

ANSWER ALL QUESTIONS IN SECTION A AND THREE QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS.

MARK ALLOCATION

QUESTION	MARKS
1.	**40**
2.	**20**
3.	**20**
4.	**20**
5.	**20**
6.	**20**
TOTAL	**100**

SECTION A [40 MARKS]

1 a) Define a PLC. [4]

b) Explain the reason for including an input/output module unit in a PLC. [4]

c) What are the characteristics of *cascade control system* [5]

d) Describe the implementation of *Human-Machine Interfaces* (HMI) in industrial processes and its importance. [4]

e) Distinguish between a *transducer* and *sensor*. [4]

f) Write a *Statement List* programme for *Siemens S12* represented by *Figure A.1.* [4]

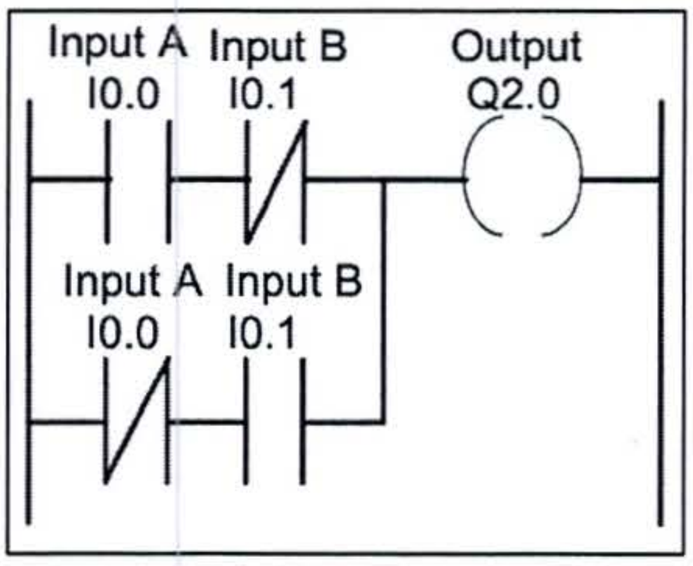

Figure A.1. Ladder logic

g) Suggest sensors which could be used in the following situations and give reasons:

i. To monitor the rate at which water flows along a pipe and giving an electrical signal related to the flow rate. [1]

ii. To monitor the pressure in a pressurised air pipe, giving a visual display of the pressure. [1]

h) Determine the overall *steady-state gain* of both *positive* and *negative feedback* systems if the closed-loop control system has a forward loop with a gain of 10 and a feedback loop with a gain of 4. [4]

i) Programmable controllers today are most often linked together in networks that together integrate plant operations. Describe the three main *types of networks* used in SCADA. [6]

j) Draw a ladder logic control circuit for the electric motor of an air compressor, controlled by two pressure switches: one switch turns the motor on when the pressure falls to 80 PSI, while the other switch turns the motor off when the pressure rises to 105 PSI. [3]

SECTION B [Answer Any Three Questions: 60 MARKS]

2. (a) Develop the relay logic diagram for a circuit that operates as follows:
   - The main switch (SW) is the emergency stop switch, which is normally closed.
   - When the red pushbutton (PR) is pressed, the red pilot light and motor one (M1) are energized. They will stay on until SW is opened.
   - When the green pushbutton (PG) is closed, both white and green pilot lights turn on, and motor one (M1) and motor two (M2) will run. They will stay on until MSW is opened. [5]

   (b) Describe the stages of designing a control system that can be used in automating an industrial process. [5]

   (c) How does a *Drum Sequencer* operate in industrial control systems? [4]

   (d) A level control system has a control valve on the inlet stream.

   i. Should the control valve be air-to-open or air-to-close? [2]

   ii. What are the signs of K_v and the process gain, K_p, which relates inflow rate to level? [2]

   iii. Should the feedback controller gain K_c be positive or negative? [2]

3. (a) All PLCs contain both RAM and ROM in varying sizes depending upon the design of the PLC. The use of a PLC's memory is determined by the design of the unit. However, all PLC memories can be subdivided into at least five major areas. [10]
   Discuss on the five major subdivisions of memory utilization and their corresponding memories in a PLC.

   (b) Determine the overall transfer function for the systems shown in Figure B.1 [6]

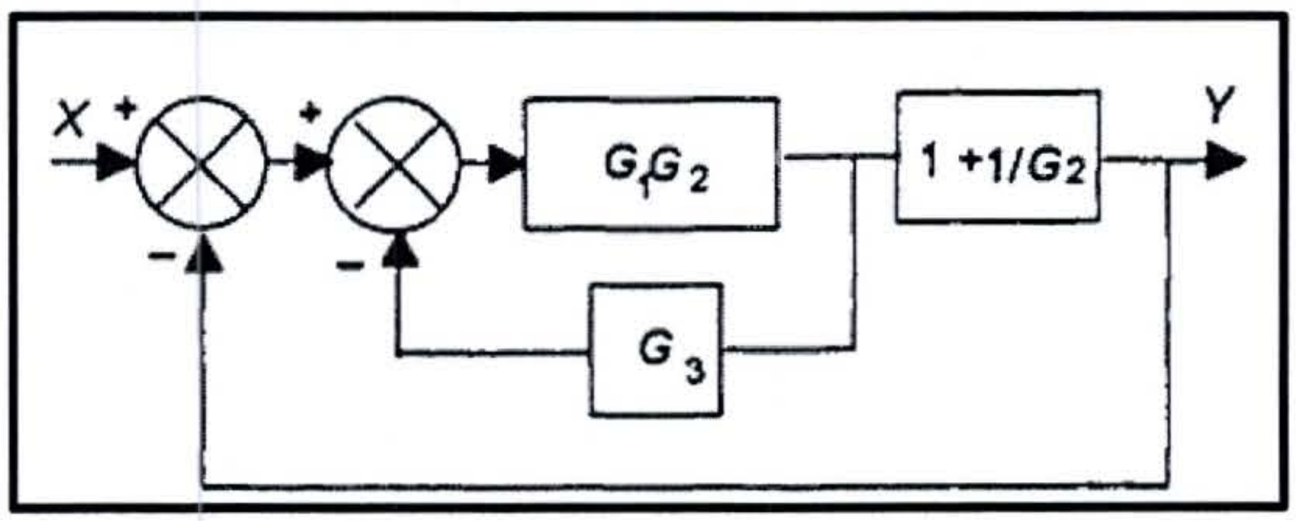

Figure B.1 Control system.

   (c) A system has a transfer function of $10/(s^2 + 4s + 9)$. Determine whether is the system under-damped, critically damped or over-damped. [4]

4. (a) What are the principles to be observed in installing a safe emergency stop system in a PLC? [3]

(b) The following Boolean expression is representing an industrial process.

$$X = \overline{(A + B\bar{A})} + \overline{(CD + \bar{A}D + C\bar{D})}$$

i. Simplify the Boolean expression. [3]

ii. Devise a PLC *ladder logic* of the simplified expression. [2]

iii. Draw the related *functional blocks programme*. [2]

iv. Write *instruction list* for the simplified expression if a *Mitsubishi* PLC was used. [3]

(c) A closed-loop negative feedback system for the control of the height of liquid in a tank by pumping liquid from a reservoir tank can be a system with a differential amplifier having a transfer function of 5, its output operating a pump with a transfer function *5/(s + 1)*. The coupled system of tanks has a transfer function, relating height in the tank to the output from the pump, of *3/(s + 1)(s+ 2)*. The feedback sensor of the height level in the tank has a transfer function of *0.1*.
Determine the overall transfer function of the system, relating the input voltage signal to the system to the height of liquid in the tank. [5]

(d) How does the function of an *overload heater* contrasts from that of the *fuses or circuit breakers?* [2]

5. (a) Examine metal-melting controlled furnace in Figure B.2 and answer the following questions:

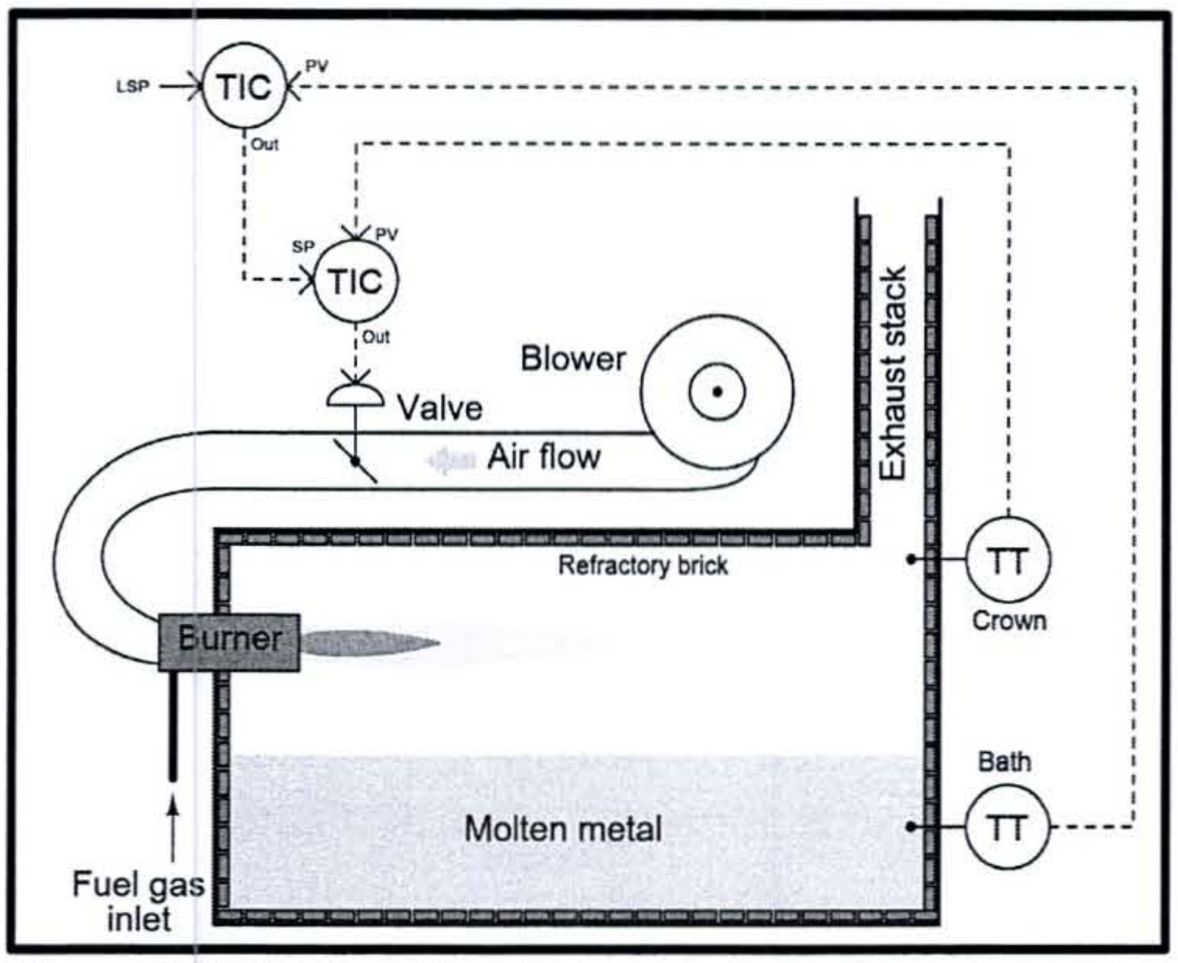

Figure B.2 Metal-melting furnace.

i Identify the control strategy being implemented and explain how it implemented in controlling the metal-melting process. [5]

ii Suggest a solution for the following problem, whereby the secondary control loop won't be driven into saturation in the event of slag on the metal surface.

Sometimes a thick layer of "slag" covers the surface of the metal, impeding heat transfer from the burner flame to the molten metal bath. The bath controller, sensing low metal temperature, sends an ever-increasing setpoint to the crown controller, raising the air temperature inside the furnace to high levels, which then shortens the life of the refractory brick. [5]

(b) Compare and contrast the operation of a *Distributed Control System* and a *Centralized Control System*. [6]

(c) Deduce a relay ladder diagram for motor control circuit which incorporates *start, stop* and *jog*. Explain what distinguishes the "*Start*" function from the "*Jog*" function and think of a practical application where this might be useful. [4]

6. (a) *Reduced Voltage Starting* connects the motor windings/terminals at lower-than-normal line voltage during the initial starting period to reduce the inrush current when the motor starts. With the aid of relay ladder diagrams, explain how motors reduced voltage starting is performed using *Autotransformer or Compensator motor starter.* [4]

(b) Examine this water filter control system in Figure B.3 , then answer the following questions:

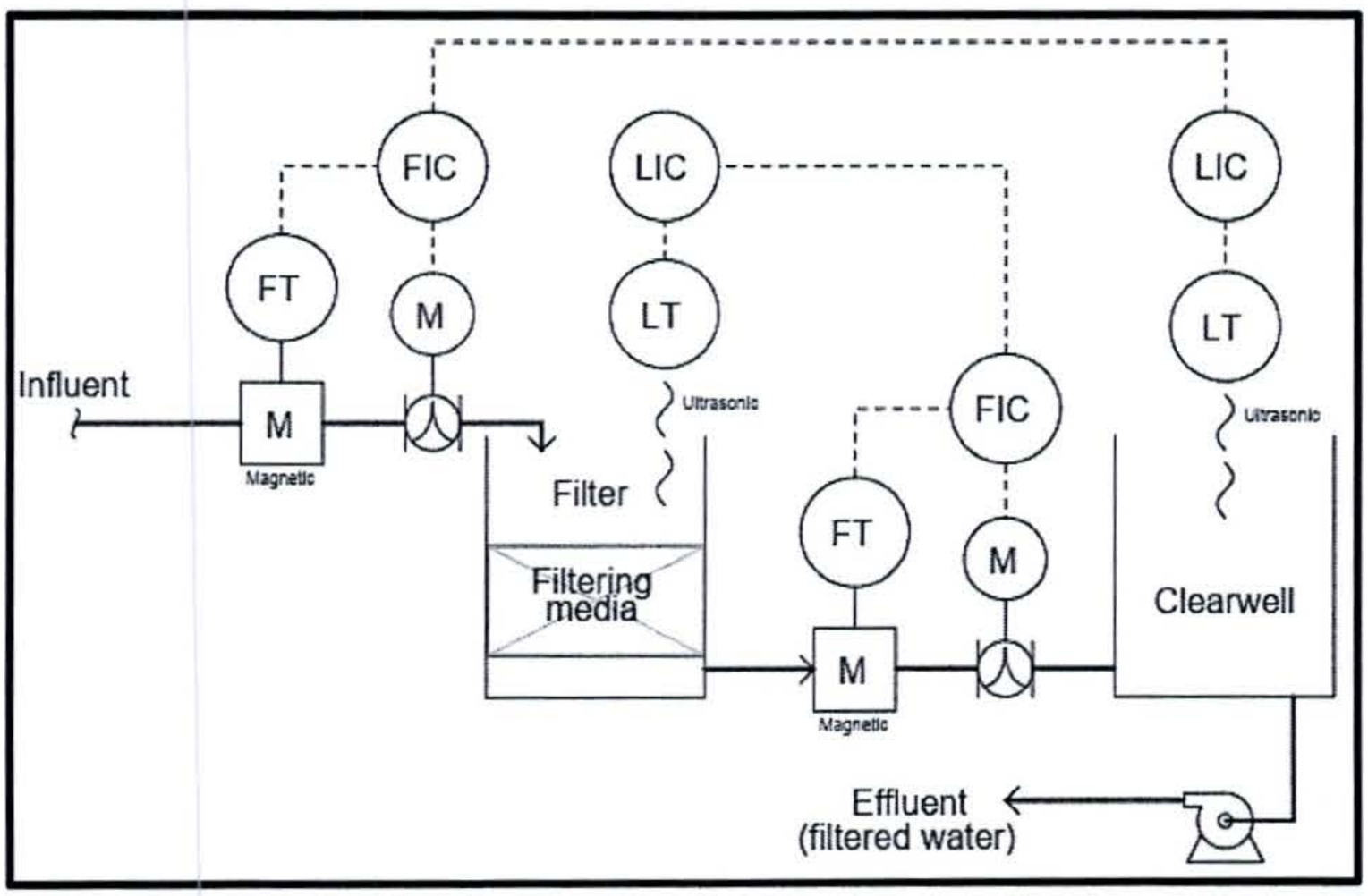

Figure B.3 Water filter control system

i. Identify all *primary* and *secondary (cascaded)* loops. [2]

ii. Describe the necessary control actions (direct/reverse) for each controller, assuming direct-acting transmitters and signal-to-open control valves. [4]

iii. Explain what will happen to the filter water level if the influent supply suddenly shuts off. [2]

iv. Explain what will happen to the clear-well reservoir water level if the influent supply suddenly shuts off? [2]

(c) Articulate the *Nyquist Stability Criterion* and illustrate it with examples of stable, marginally stable and unstable systems. [2]

(d) With the aid of diagrams and equations describe the Modified Derivative Controller. [4]

++++++++++++++++++++++++++***END OF EXAMINATION PAPER***++++++++++++++++++++++++++