

2501/302 2508/302

2503/302 2509/302

CONTROL SYSTEMS AND INSTRUMENTATION

June/ July 2022

Time: 3 Hours



THE KENYA NATIONAL EXAMINATIONS COUNCIL

**DIPLOMA IN MECHANICAL ENGINEERING
(PRODUCTION OPTION)**

(WELDING AND FABRICATION OPTION)

(CONSTRUCTION PLANT OPTION)

DIPLOMA IN AUTOMOTIVE ENGINEERING

MODULE III

CONTROL SYSTEMS AND INSTRUMENTATION

3 hours

INSTRUCTIONS TO CANDIDATES

You should have the following for this examination:

Answer booklet;

Non-programmable Scientific calculator;

Drawing instruments.

This paper consists of EIGHT questions in TWO sections; A and B.

Answer FIVE questions by choosing at least TWO questions from each section in the answer booklet provided.

All questions carry equal marks.

Maximum marks for each part of a question are as indicated.

Candidates should answer the questions in English.

This paper consists of 8 printed pages.

Candidates should check the question paper to ascertain that all the pages are printed as indicated and that no questions are missing.

SECTION A: CONTROL SYSTEMS

Answer at least *TWO* questions from this section.

1. (a) State **three** advantages of open-loop control systems over closed-loop control systems. (3 marks)
- (b) Draw a labelled block diagram of a closed loop control system (4 marks)
- (c) **Figure 1** shows a block diagram of a control system. Determine its:
 - (i) canonical form representation;
 - (ii) closed loop transfer function.

(7 marks)

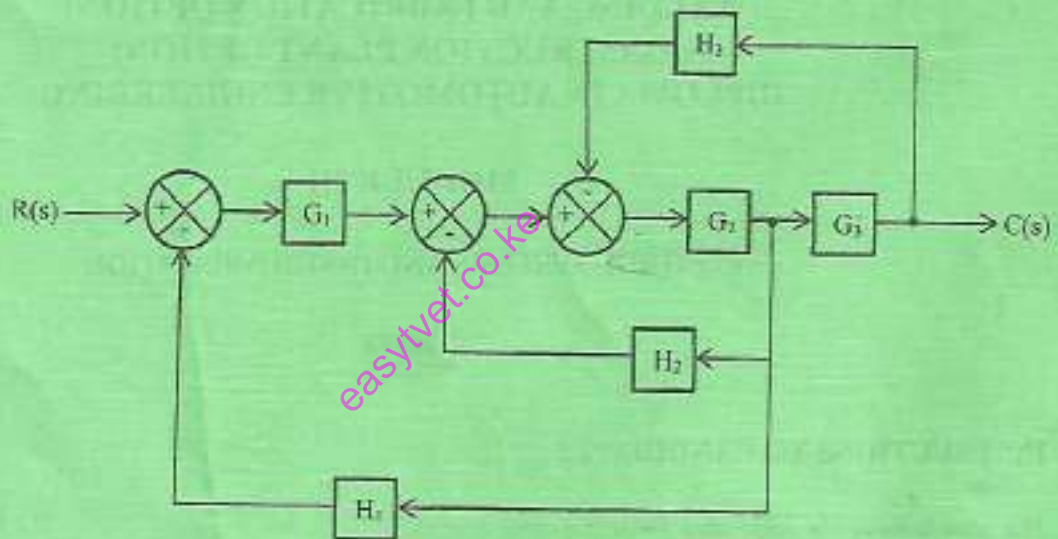


Fig. 1

- (d) Figure 2 shows a mechanical system.
- (i) Write the differential equations of its dynamics;
- (ii) Draw the force-voltage analogous circuit.

(6 marks)

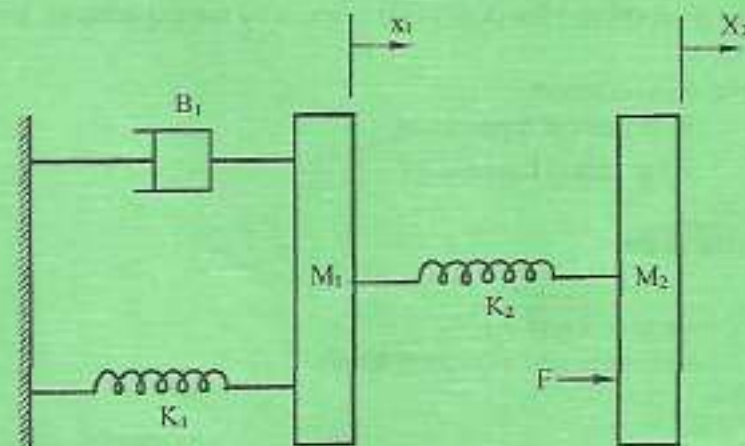


Fig. 2

2. (a) Distinguish between unipolar and bipolar stepper motors. (2 marks)
- (b) With the aid of a construction diagram, describe the operation of a 15° three phase variable reluctance stepper motor. (6 marks)
- (c) Figure 3 shows a block diagram of a control system.
- (i) Draw the equivalent signal flow graph;
- (ii) Using Mason's gain formula, determine its transfer function.

(9 marks)

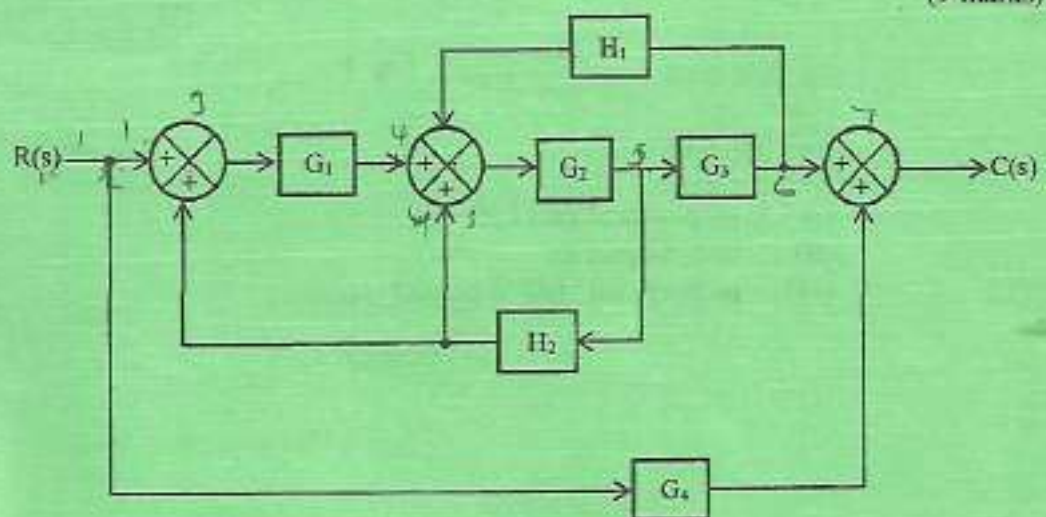


Fig. 3

- (d) A hydraulic cylinder of diameter 8 cm is supplied with hydraulic oil at a pressure of 700 kpa. Determine the force exerted on the piston. (3 marks)

2501/302 2508/302

3

2503/302 2509/302

June/ July 2022

Turn over

3. (a) Describe an ON-OFF process controller. (3 marks)

(b) A liquid level control system converts a change of level of 1 - 2 mA into a 4 - 20 mA control signal. A microswitch serves as an ON - OFF controller to open or close an inlet valve. The switch closes at 14 mA and opens at 10 mA. The relationship between liquid level (b) and the current (I) is given by the expression: $b = kI + b_0$.

where: k = constant
 b = current liquid level
 b_0 = initial liquid level

Determine the:

- value of k and b_0 ;
- maximum and minimum levels.

(7 marks)

(c) Figure 4 shows a proportional-integral controller.

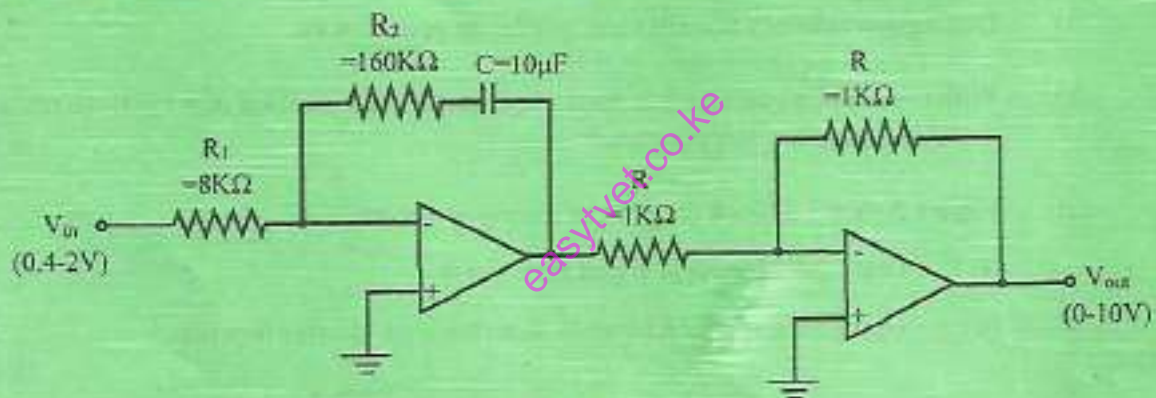


Fig. 4

Determine the:

- proportional gain k_p ;
- integral gain k_i ;
- proportional band in percentage.

(6 marks)

- (d) Figure 5 shows an error input signal of a Proportional Derivative (PD) controller. Draw the response curve of the controller. (4 marks)

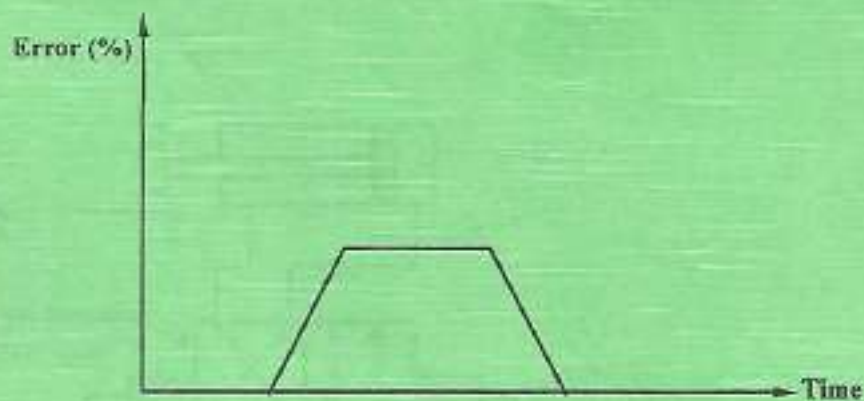


Fig. 5

4. (a) Distinguish between process control system and servomechanism. (2 marks)
- (b) Describe a Direct Digital Control (DDC) system. (4 marks)
- (c) Figure 6 shows a PLC ladder diagram program. Write a corresponding mistubishi instruction list program. (6 marks)

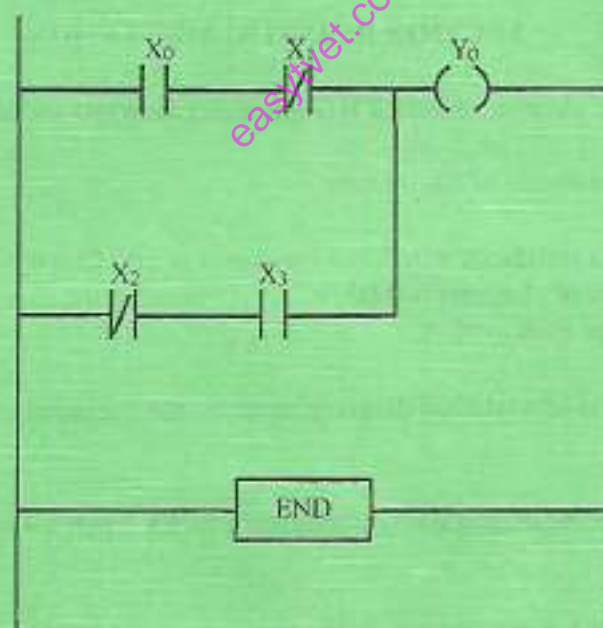


Fig. 6

- (d) Figure 7 shows a PLC controlled cylinder. When switch Sw_1 is closed, piston A will extend out of the cylinder (A+). When switch Sw_2 is closed, piston A will retract into the cylinder (A-). Draw the ladder diagram for this process.

(8 marks)

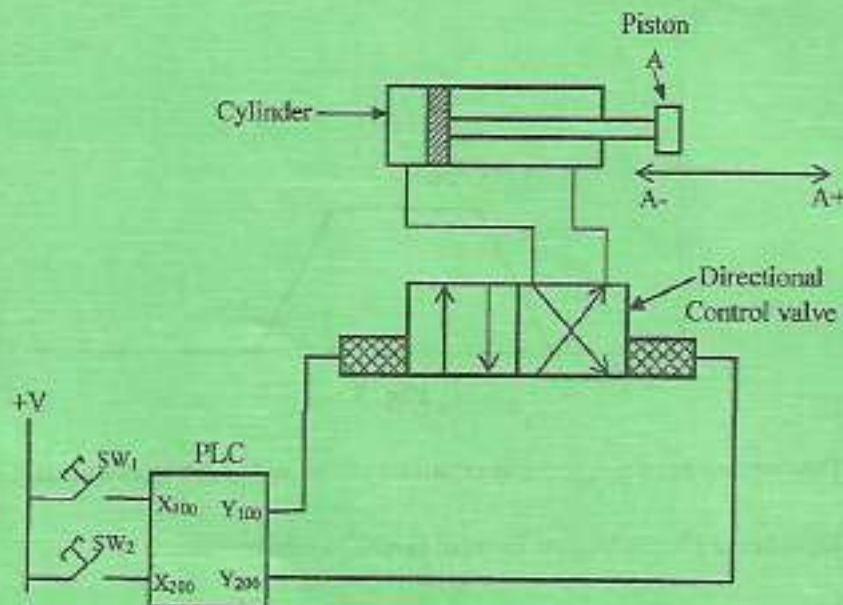


Fig. 7

SECTION B: INSTRUMENTATION

Answer at least TWO questions from this section.

5. (a) State three merits of thermistors. (3 marks)
- (b) A platinum resistance wire has a resistance of 100Ω at 0°C . The temperature co-efficient of platinum is $0.0039 \text{ } ^\circ\text{C}^{-1}$. Determine the change in resistance when temperature rises to 30°C . (3 marks)
- (c) With the aid of a labelled diagram, describe the operation of an ultrasonic liquid level sensor. (6 marks)
- (d) A piezoelectric crystal with dimensions $2 \text{ mm} \times 2 \text{ mm} \times 1 \text{ mm}$ has the following properties:
- charge sensitivity = 20 pC/N ;
 - Young's modulus = $8.6 \times 10^{10} \text{ N/m}^2$;
 - Permittivity = $40.6 \times 10^{-12} \text{ F/m}$;

The crystal is subjected to a strain of 10×10^{-6} . Determine the:

- (i) force applied;
- (ii) charge generated;
- (iii) voltage generated.

(8 marks)

6. (a) State **three** advantages of semiconductor strain gauges over metallic strain gauges. (3 marks)
- (b) A copper wire having an initial resistance of 275Ω and a gauge factor of 2.7 is subjected to a strain of 5.5×10^{-3} . Determine the resistance of the wire after the strain. (3 marks)
- (c) With that aid of a labelled diagram, describe the operation of a resistive hygrometer. (6 marks)
- (d) **Figure 8** shows a capacitive displacement sensor. The two metal cylinders are separated by a plastic sheath of thickness 1 mm and dielectric constant of 2.5. Determine the:
- (i) sensitivity of the sensor;
 - (ii) change in capacitance when h varies from 1 to 2 cm.

(8 marks)

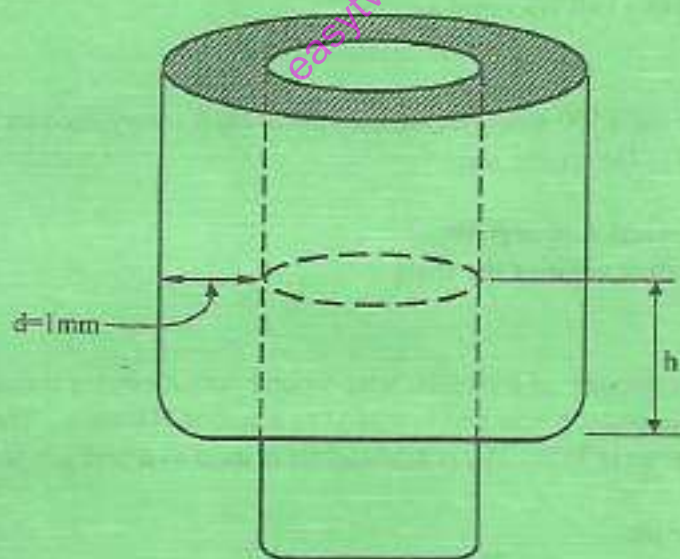


Fig. 8

7. (a) State three factors considered when selecting an instrument. (3 marks)
- (b) With the aid of a labelled diagram, describe the operation of a strain gauge pressure sensor (6 marks)
- (c) An accelerometer has a mass of 0.05 kg and a spring constant of 3.0×10^3 N/m. The maximum mass displacement is ± 0.02 m. Determine the:
- (i) maximum measurable acceleration;
 - (ii) natural frequency. (4 marks)
- (d) (i) Describe Seebeck effect with reference to thermocouples.
- (ii) A wattmeter under calibration indicates a full-scale reading of 120 W on its 120 V, 1 A range. The measured current and voltage are 1 A and 114 V respectively. Determine the wattmeter percentage error. (7 marks)
8. (a) Define viscosity. (2 marks)
- (b) Describe the working principle of each of the following types of viscometers:
- (i) orifice viscometer;
 - (ii) falling ball viscometer. (4 marks)
- (c) A counter for a 500-slot incremental optical shaft rotary encoder has a value of 101100011. Determine the:
- (i) resolution in degrees;
 - (ii) current angle of the shaft. (6 marks)
- (d) A resistive element of a circular wire-wound potentiometer is made from a 10m of 100 Ω /m resistance wire and is wound as a coil of 200 turns. The range of the potentiometer is 350° . The potentiometer is used as a position sensor.
- Determine the:
- (i) total resistance of the potentiometer wire;
 - (ii) resistance per turn;
 - (iii) resolution of the potentiometer in ohms;
 - (iv) resolution in degrees. (8 marks)

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