AC generators and flux linkage graphs

Electromagnetism 5 Testing a research buoy generator

35–40 minutes independent work + 15–20 minutes review

OCR A H556 | A-level physics | Module 6 | 35 marks

Specification points covered

6.3.3(a–c), (d)(i): magnetic flux and flux linkage; induced e.m.f. and Faraday's and Lenz's laws.

6.3.3(e): a simple a.c. generator. Apply prior skills in period, frequency, gradients and energy transfers.

Use $\varepsilon = -\Delta(N\Phi)/\Delta t$ for an average e.m.f. Instantaneous e.m.f. is the negative gradient of the flux-linkage–time graph. Treat the stated field as uniform.

Use a calculator and your OCR A data booklet. Show working, units and directions where relevant.

1 Power for a wave-monitoring buoy

A research buoy uses wave motion to drive a generator through a gearbox and flywheel. The tests below use a steady laboratory motor; do not assume the real waves produce constant rotation.

The rectangular coil has 180 turns, area 0.0120 m^2 per turn, and rotates in a uniform field of flux density 0.0900 T. Ignore resistance unless a later question states otherwise.

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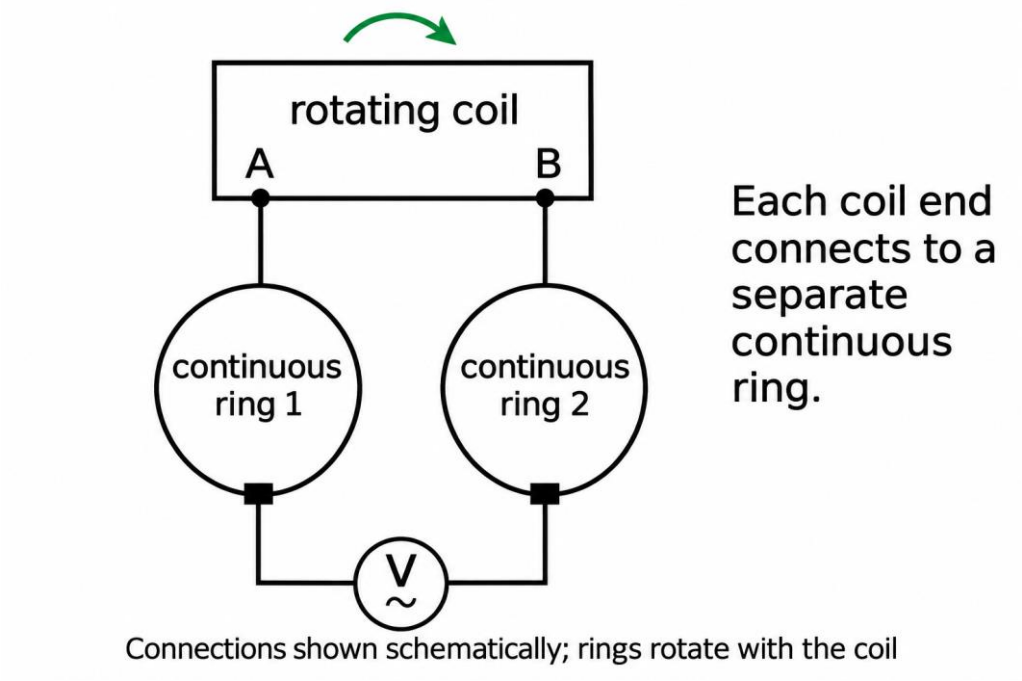


Figure 1 Separate continuous-ring connections; electrical schematic

1(a) A rotating coil is connected to two continuous slip rings and two brushes. Explain the roles of the rings and brushes. **[2 marks]**

1(b) State the main energy transfer when the generator supplies the buoy's sensors. **[1 mark]**

2 Orientation and alternating output

2(a) At t = 0 the coil's area normal is parallel to B. Calculate the magnetic flux through one turn and the flux linkage. Explain why these are different quantities. **[2 marks]**

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2(b) The coil turns through 90° from its starting position. State the new flux linkage and explain the orientation used. **[1 mark]**

2(c) Explain why the magnitude of the e.m.f. is greatest when the flux linkage is zero, rather than when the flux linkage is greatest. **[2 marks]**

2(d) Explain why the e.m.f. reverses during each full rotation. **[1 mark]**

3 Average e.m.f. is not the peak e.m.f.

3(a) The coil rotates at 12.0 Hz. Calculate its period and the time taken to turn through 60°. **[2 marks]**

3(b) Calculate the flux linkage after a 60° turn from t = 0. **[1 mark]**

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3(c) For this first 60° turn, calculate the signed average e.m.f. Use $\varepsilon_{av} = -\Delta(N\Phi)/\Delta t$ with the signed linkage just defined. **[2 marks]**

3(d) A pupil calls the answer to 3(c) “the peak e.m.f.” Explain why this conclusion is not justified. **[1 mark]**

4 Construct and read the graphs

Keep f = 12.0 Hz. Use the unrounded model values where helpful. The graph data refer to the ideal induced e.m.f., with no load connected.

Table 1 One steady rotation; rounded values

Time / ms	NΦ / Wb	ε / V
0	+0.1944	0
20.83	0	+14.66
41.67	−0.1944	0
62.50	0	−14.66
83.33	+0.1944	0

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4(a) Use Table 1 to sketch smooth flux-linkage–time and e.m.f.–time graphs for one turn. Label both axes, the extrema and the quarter-period times. The tabulated e.m.f. values follow the declared sign convention. **[3 marks]**

4(b) A tangent to the linkage graph at T/4 passes through the points (18.00 ms, +0.04153 Wb) and (23.00 ms, −0.03176 Wb). Use these tangent points to estimate the instantaneous e.m.f. at T/4. **[2 marks]**

4(c) The steady rotation frequency is doubled. State the changes to the linkage amplitude, the period and the peak e.m.f. **[2 marks]**

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4(d) Calculate the signed area under the e.m.f.–time graph over the first half-turn. Explain why its area over a complete turn is zero although energy can be transferred to a load. **[2 marks]**

5 Connect the load

5(a) When a resistive load is connected, the motor needs a greater driving torque to keep the same speed. Explain this using Lenz's law and energy conservation. **[2 marks]**

5(b) At one instant the terminal p.d. is +8.00 V and the outward load current is +0.450 A. Calculate the instantaneous power transferred to the load. **[1 mark]**

5(c) Over many cycles the mean electrical output is 8.00 W and mean mechanical input is 13.0 W. Calculate the efficiency. Explain why peak e.m.f. × peak current is not generally the mean power. **[2 marks]**

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6 Choose a viable design

6(a) For the same field and coil area, the peak induced e.m.f. is $\varepsilon_0 = 2\pi fNBA$. Calculate it for each proposed design: P: N = 180, f = 10.0 Hz; Q: N = 120, f = 14.0 Hz; R: N = 180, f = 14.0 Hz. **[2 marks]**

6(b) The buoy requires a no-load peak e.m.f. from 12.0 V to 16.0 V and a frequency from 10.0 Hz to 14.0 Hz, inclusive. Select a design and justify it against both requirements. **[1 mark]**

6(c) In a separate loaded test, the instantaneous induced e.m.f. is +10.0 V, the coil resistance is 2.00 Ω, and the outward current is +0.400 A. Calculate the terminal p.d. Assume $\varepsilon = V + Ir$ at this instant. **[1 mark]**

6(d) Correct both claims: “Maximum flux means maximum e.m.f.” and “A faster generator changes only the frequency, not the amplitude.” **[2 marks]**

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