Parallel plate capacitors

Electric fields 3 A robotic gripper's capacitive sensor

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

OCR A H556 | A-level physics | Module 6 | 44 marks

Specification points covered

6.2.3(a–b) Uniform fields, parallel plates, permittivity and relative permittivity.

6.1.1(a–b), 6.1.2(b) Capacitance, plate charge and stored energy.

Use $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}. 1 pF = 10^{-12} F; 1 nC = 10^{-9} C.

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

1 Read the sensor

A robotic gripper senses compression using two electrodes separated by an insulating pad. The overlap area is 40.0 cm^2, the initial thickness is 1.20 mm and the pad's relative permittivity is 3.20.

Initially a 3.00 V supply is connected. Treat the pad as completely filling the gap. Assume fixed overlap, constant ε_r, parallel plates and negligible edge effects unless a question asks you to evaluate these assumptions.

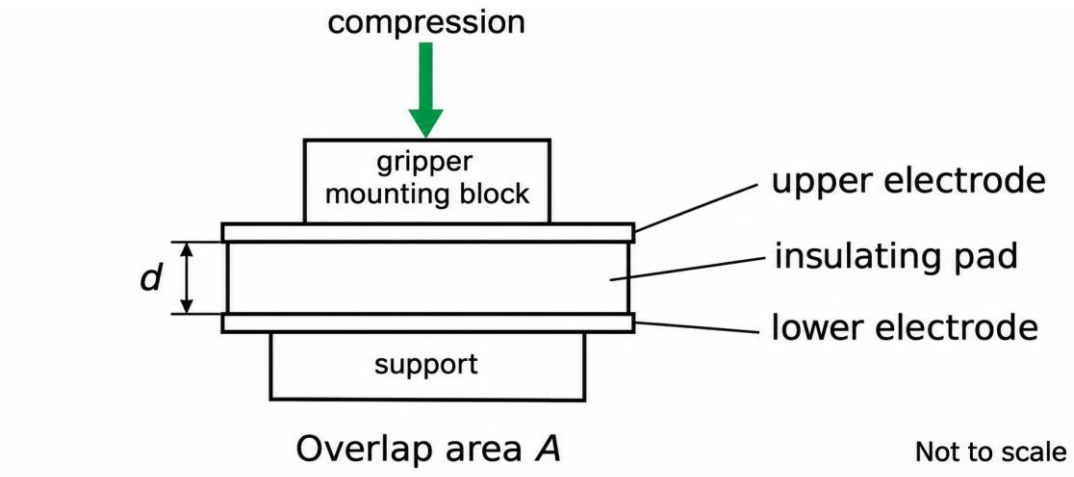


Figure 1 Capacitive compression sensor

1(a) In $C = \varepsilon_0\varepsilon_r A/d$, explain what A and d represent for the sensor in Figure 1. **[1 mark]**

1(b) Convert the overlap area of 40.0 cm^2 and the initial gap of 1.20 mm into SI units. **[2 marks]**

2 Find the baseline reading

2(a) Calculate the capacitance if the same geometry had air between its plates. Take the relative permittivity of air as 1.00. **[1 mark]**

2(b) Calculate the capacitance with the insulating pad present and explain the numerical relationship to your air-gap result. **[2 marks]**

2(c) Find the magnitude of charge on either electrode at 3.00 V. Explain how this can be non-zero even if the total net charge on the two-electrode capacitor is zero. **[2 marks]**

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

2(d) Calculate the initial electric field magnitude and the energy stored in the sensor. **[2 marks]**

3 Choose the electrode geometry

3(a) A redesigned pad has d = 1.00 mm and ε_r = 3.20. Find the minimum overlap area needed for C = 120 pF. Give the answer in cm^2. **[2 marks]**

3(b) Two fully overlapping electrode pairs are available: rectangles 80.0 mm by 50.0 mm, or circles of diameter 75.0 mm. At the redesigned thickness, which reaches at least 120 pF? Justify using the areas or capacitances. **[2 marks]**

3(c) For an ideal sensor with fixed geometry and dielectric, does increasing its supply p.d. increase its capacitance? Explain. **[1 mark]**

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

4 Compress the connected sensor

4(a) Return to the original 40.0 cm^2 sensor. Its gap decreases from 1.20 mm to 0.900 mm while the 3.00 V supply stays connected. Calculate its new capacitance. **[1 mark]**

4(b) Calculate the new plate-charge magnitude and the increase in that magnitude. Explain where the additional charge transfer comes from. **[3 marks]**

4(c) Calculate the new field magnitude and state its ratio to the original field. **[1 mark]**

4(d) Find the new stored energy and explain whether it rises or falls. Do not equate this stored-energy change to the gripper's mechanical work. **[2 marks]**

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

5 Compare a disconnected sensor

5(a) Reset the original sensor to 1.20 mm and charge it to 3.00 V. Disconnect both supply and meter, so its plate-charge magnitude remains fixed. Then compress it to 0.900 mm. Find its new p.d. **[2 marks]**

5(b) Calculate the stored energy after this isolated compression and compare it with the initial stored energy. **[2 marks]**

5(c) Show that the field stays unchanged in this ideal isolated compression. Then state how V and E would change if, instead, ε_r doubled at a fixed gap and fixed charge. **[3 marks]**

6 Test the geometry model

Use the separate rigid-air-plate apparatus in Figure 2 for this investigation.

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

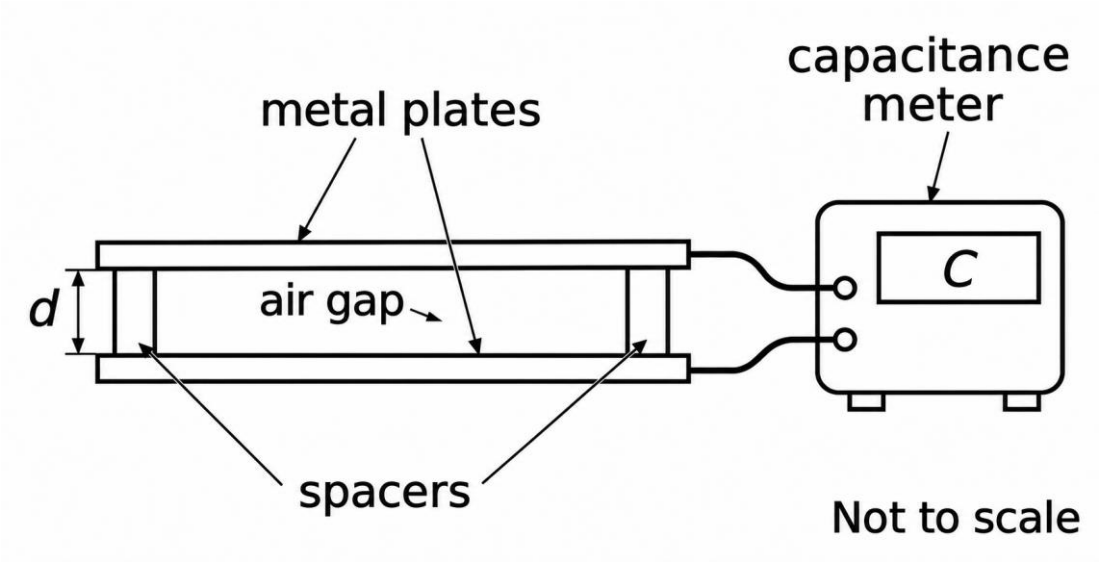


Figure 2 Rigid air-gap test

6(a) Figure 2 shows a separate rigid-air-plate investigation. Describe how to vary d and measure C while controlling two variables that matter to the model. Include a useful way to measure a small gap. **[3 marks]**

6 Process the air-gap readings

For this separate air-gap test, the leads are kept fixed and the stray capacitance is approximately constant.

Table 1

d / mm	C_{meter} / pF
1.00	47.4
1.50	35.6
2.00	29.7

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

d / mm	C_{meter} / pF
2.50	26.2
3.00	23.8

6(b) Table 1 contains results for A = 4.00 × 10^{-3} m^2. The meter includes a constant stray capacitance: $C_{meter} = \varepsilon A/d + C_{stray}$. Sketch C_{meter} against 1/d and label the meaning of its intercept. **[2 marks]**

6(c) Use the readings at d = 1.00 mm and 2.00 mm to determine the gradient in F m, then infer ε for the air. **[2 marks]**

6(d) Explain why repeating each meter reading and taking an average does not remove a constant stray capacitance. **[1 mark]**

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk

7 Interpret the gripper reading

7(a) The gripper's original $\varepsilon_r = 3.20$ sensor now gives a meter reading of 145 pF. Its separately calibrated parallel stray capacitance is 25 pF. Determine the pad thickness. **[3 marks]**

7(b) Compression is sufficient when $d \leq 0.950$ mm. The meter's uncertainty is ±1 pF; take all other values as exact for this check. Is sufficient compression guaranteed? Use the limiting reading. **[2 marks]**

7(c) Explain two reasons why a real compressed pad might give a different thickness from the ideal calculation, even with a perfect capacitance meter. **[2 marks]**

Continue your physics journey
Videos, practice and support for your next step
www.physicsuk.co.uk