APPENDIX

C

FUNDAMENTALS OF ENGINEERING (FE) EXAMINATION

C.1 INTRODUCTION

The *Fundamentals of Engineering* (FE) examination[1] is one of four steps to be completed toward registering as a Professional Engineer (PE). Each of the 50 states in the United States has laws that regulate the practice of engineering; these laws are designed to ensure that registered professional engineers have demonstrated sufficient competence and experience. The same exam is administered at designated times throughout the country, but each state's Board of Registration administers the exam and supplies information and registration forms. **Additional information is available on the NCEES website.**

FIND IT ON THE WEB

Four steps are required to become a Professional Engineer:

1. *Education.* Usually this requirement is satisfied by completing a B.S. degree in engineering from an accredited college or university.
2. *Fundamentals of Engineering examination.* One must pass an 8-hour examination described in Section C.2.

[1] This exam used to be called *Engineer in Training.*

3. *Experience.* Following successful completion of the Fundamentals of Engineering examination, two to four years of engineering experience are required.
4. *Principles and practices of engineering examination.* One must pass a second 8-hour examination, also known as the Professional Engineer (PE) examination, which requires in-depth knowledge of one particular branch of engineering.

This appendix provides a review of the background material in electrical engineering required in the Electrical Engineering part of the FE exam. This exam is prepared by the National Council of Examiners for Engineering and Surveying[2] (NCEES).

C.2 EXAM FORMAT AND CONTENT

FIND IT ON THE WEB

The FE exam is a two-part national examination, administered by the **National Council of Examiners for Engineers and Surveyors** (NCEES) and given twice a year (in April and October). The exam is divided into two four-hour sessions, consisting of 120 questions in the four-hour morning session, and 60 questions in the four-hour afternoon session. The morning session covers general background in 12 different areas, one of which is *Electricity and Magnetism*. The afternoon session requires the examinee to choose among seven modules—Chemical, Civil, Electrical, Environmental, Industrial, Mechanical and, Other/General Engineering.

C.3 THE ELECTRICITY AND MAGNETISM SECTION OF THE MORNING EXAM

The *Electricity and Magnetism* part of the morning session consists of approximately 9 percent of the morning session, and covers the following topics:

A. Charge, energy, current, voltage, power
B. Work done in moving a charge in an electric field (relationship between voltage and work)
C. Force between charges
D. Current and voltage laws (Kirchhoff, Ohm)
E. Equivalent circuits (series, parallel)
F. Capacitance and inductance
G. Reactance and impedance, susceptance and admittance
H. AC circuits
I. Basic complex algebra

The remainder of Appendix C contains a review of the electric circuits portion of the FE examination, including references to the relevant material in the book. In addition, Appendix C also contains a collection of sample problems—some including a full explanation of the solution, some with answers supplied separately.

C.4 REVIEW FOR THE ELECTRICITY AND MAGNETISM SECTION OF THE MORNING EXAM

A. Charge, energy, current, voltage and power.

B. Work done in moving a charge in an electric field (relationship between voltage and work)

[2] P.O. Box 1686 (1826 Seneca Road), Clemson, SC 29633-1686.

C. Force between charges

The basic definitions of these quantities and relevant examples can be found in Chapter 2 and in any undergraduate physics textbook. The following example problems will further assist you in reviewing the material.

CHECK YOUR UNDERSTANDING

A.1 Determine the total charge entering a circuit element between $t = 1$ s and $t = 2$ s if the current passing through the element is $i = 5t$.

A.2 A lightbulb sees a 3-A current for 15 s. The lightbulb generates 3 kJ of energy in the form of light and heat. What is the voltage drop across the lightbulb?

A.3 How much energy does a 75-W electric bulb consume in six hours?

B.1 Find the voltage drop v_{ab} required to move a charge q from point a to point b if $q = -6$ C and it takes 30 J of energy to move the charge.

C.1 Two 2-C charges are separated by a dielectric with thickness of 4 mm, and with dielectric constant $\varepsilon = 10^{-12}$ F/m. What is the force exerted by each charge on the other?

C.2 The magnitude of the force on a particle of charge q placed in the empty space between two infinite parallel plates with a spacing d and a potential difference V is proportional to:

(a) qV/d^2 (b) qV/d (c) qV^2/d (d) q^2V/d (e) q^2V^2/d

Answers: **A.1:** $q = \int_{t=1}^{t=2} i\,dt = \int_{t=1}^{t=2} 5t\,dt = \left(\frac{5t^2}{2}\right)\Big|_{t=1}^{t=2} = 7.5$ C

A.2: The total charge is $\Delta q = i\Delta t = 3 \times 15 = 45$ C. The voltage drop is

$$v = \frac{\Delta w}{\Delta q} = \frac{3 \times 10^3}{45} = 66.67 \text{ V}$$

A.3: The energy used is $w = pt = 75\,[W] \times 6\,[h] = 75\,[W] \times 6 \times 3600\,[s]\,450 = 1.62$ MJ

B.1: The voltage drop is $v_{ab} = \frac{w}{q} = \frac{30}{-6} = -5$ V

C.1: $F = \frac{q_1 q_2}{4\pi\varepsilon r^2} = \frac{(2 \times 10^{-3}) \times (2 \times 10^{-3})}{4\pi \times 10^{-12} \times (4 \times 10^{-3})^2} = 2 \times 10^{10}$ N

C.2: Answer is (a), since this is the only term that has a distance squared term in the denominator.

D. Current and voltage laws (Kirchhoff, Ohm)

The material related to this section is covered in Chapter 2, Sections 2, 3, 4 and 6. Examples 2.3, 2.4, 2.6, 2.7, 2.8, 2.9, 2.10, and the related *Check Your Understanding* exercises will help you review the necesssary material.

E. Equivalent circuits

The analysis of DC circuits forms the foundation of electrical engineering. Chapters 2 and 3 cover this material with a wealth of examples. The following exercises illustrate the general type of questions that might be encountered in the FE exam.

CHECK YOUR UNDERSTANDING

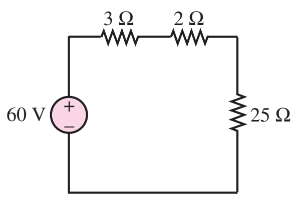

Figure E.1

E.1 Assuming the connecting wires and the battery have negligible resistance, the voltage across the 25-Ω resistance in Figure E.1 is

a. 25 V b. 60 V c. 50 V d. 15 V e. 12.5 V

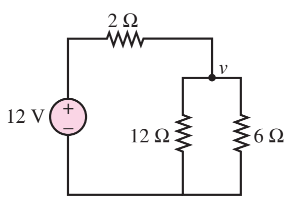

Figure E.2

E.2 Assuming the connecting wires and the battery have negligible resistance, the voltage across the 6-Ω resistor in Figure E.2 is

a. 6 V b. 3.5 V c. 12 V d. 8 V e. 3 V

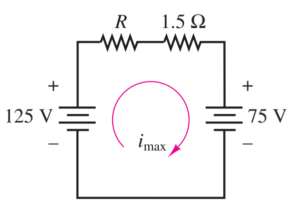

Figure E.3

E.3 In Figure E.3, A 125-V battery charger is used to charge a 75-V battery with internal resistance of 1.5 Ω. If the charging current is not to exceed 5 A, the minimum resistance in series with the charger must be

a. 10 Ω b. 5 Ω c. 38.5 Ω d. 41.5 Ω e. 8.5 Ω

Answers: **E.1:** This problem calls for application of the voltage divider rule, discussed in Section 2.6. Applying the voltage divider rule to the circuit of Figure E.2, we have

$$v_{25\Omega} = 60\left(\frac{25}{3+2+25}\right) = 50\text{ V}$$

Thus, the answer is c.

E.2: This problem can be solved most readily by applying nodal analysis (Section 3.1), since one of the node voltages is already known. Applying KCL at the node v, we obtain

$$\frac{12-v}{2} = \frac{v}{6} + \frac{v}{12}$$

This equation can be solved to show that $v = 8$ V. Note that it is also possible to solve this problem by mesh analysis (Section 3.2). You are encouraged to try this method as well.

E.3: The circuit of Figure E.3 describes the charging arrangement. Applying KVL to the circuit of Figure E.3, we obtain

$$i_{max}R + 1.5i_{max} - 125 + 75 = 0$$

and using $i = i_{max} = 5$ A, we can find R from the following equation:

$$5R + 7.5 - 125 + 75 = 0$$

$$R = 8.5\ \Omega$$

Thus, e is the correct answer.

F. Capacitance and inductance

The material on capacitance and inductance pertains to two basic areas: energy storage in these elements and transient response of the circuits containing these elements. The exercises below deal with the former part (covered in Chapter 4); the latter is covered in Chapter 5 of the book.

CHECK YOUR UNDERSTANDING

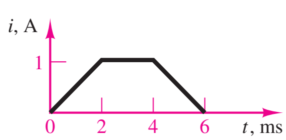

Figure F.1

F.1 A coil with inductance of 1 H and negligible resistance carries the current shown in Figure F.1. The maximum energy stored in the inductor is

a. 2 J b. 0.5 J c. 0.25 J d. 1 J e. 0.2 J

F.2 The maximum voltage that will appear across the coil is

a. 5 V b. 100 V c. 250 V d. 500 V e. 5,000 V

Answers: **F.1:** The energy stored in an inductor is $W = \frac{1}{2}Li^2$ (see Section 4.1). Since the maximum current is 1 A, the maximum energy will be $W_{max} = \frac{1}{2}Li^2_{max} = \frac{1}{2}$ J. Thus, b is the correct answer.

F.2: Since the voltage across an inductor is given by $v = L(di/dt)$, we need to find the maximum (positive) value of di/dt. This will occur anywhere between $t = 0$ and $t = 2$ ms. The corresponding slope is

$$\left.\frac{di}{dt}\right|_{max} = \frac{1}{2 \times 10^{-3}} = 500$$

Therefore $v_{max} = 1 \times 500 = 500$ V, and the correct answer is d.

G. Reactance and impedance, susceptance and admittance

The material related to this section is covered in Chapter 4, Section 4. Examples 4.12, 4.13, 4.14, 4.15, and the related *Check Your Understanding* exercises will help you review the necessary material.

H. AC circuits

The material related to basic AC circuits is covered in Chapter 4, Sections 2 and 4. Examples 4.8, 4.9, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, and the related *Check Your Understanding* exercises will help you review the necessary material. In addition, material on AC power may be found in Chapter 7, Sections 1 and 2. Examples 7.1 through 7.11 and the accompanying *Check Your Understanding* exercises will provide additional review material. The rest of this section offers a number of sample FE exam problems.

CHECK YOUR UNDERSTANDING

H.1 A voltage sine wave of peak value 100 V is in phase with a current sine wave of peak value 4 A. When the phase angle is 60° later than a time at which the voltage and the current are both zero, the instantaneous power is most nearly

a. 300 W b. 200 W c. 400 W d. 150 W e. 100 W

H.2 A sinusoidal voltage whose amplitude is $20\sqrt{2}$ V is applied to a 5-Ω resistor. The root-mean-square value of the current is

a. 5.66 A b. 4 A c. 7.07 A d. 8 A e. 10 A

H.3 The magnitude of the steady-state root-mean-square voltage across the capacitor in the circuit of Figure H.1 is

a. 30 V b. 15 V c. 10 V d. 45 V e. 60 V

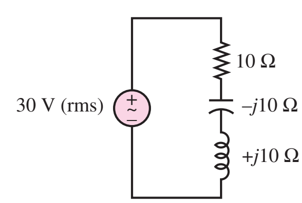

Figure H.1

Answers: **H.1:** As discussed in Section 7.1, the instantaneous AC power $p(t)$ is

$$p(t) = \frac{VI}{2}\cos\theta + \frac{VI}{2}\cos(2\omega t + \theta_V + \theta_I)$$

In this problem, when the phase angle is 60° later than a "zero crossing," we have $\theta_V = \theta_I = 0$, $\theta = \theta_V - \theta_I = 0$, $2\omega t = 120°$. Thus, we can compute the power at this instant as

$$p = \frac{100 \times 4}{2} + \frac{100 \times 4}{2}\cos(120°) = 300 \text{ W}$$

The correct answer is a.

H.2: From Section 4.2, we know that

$$V_{\text{rms}} = \frac{V}{\sqrt{2}} = \frac{20\sqrt{2}}{\sqrt{2}} = 20 \text{ V}$$

Thus, $I_{\text{rms}} = 20/5 = 4$ A. Therefore, b is the correct answer.

H.3: This problem requires the use of impedances (Section 4.4). Using the voltage divider rule for impedances, we write the voltage across the capacitor as

$$\mathbf{V} = 30\angle 0° \times \frac{-j10}{10 - j10 + j10}$$

$$= 30\angle 0° \times (-j1) = 30\angle 0° \times 1\angle -90° = 30\angle 90°$$

Thus, the rms amplitude of the voltage across the capacitor is 30 V, and a is the correct answer. Note the importance of the phase angle in this kind of problem.

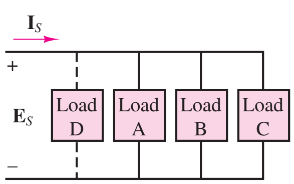

Figure H.2

The next set of questions (Exercises H.4 to H.8) pertain to single-phase AC power calculations and refer to the single-phase electrical network shown in Figure H.2. In this figure, $\mathbf{E}_S = 480\angle 0°$ V; $\mathbf{I}_S = 100\angle -15°$ A; $\omega = 120\pi$ rad/s. Further, load A is a bank of single-phase induction machines. The bank has an efficiency η of 80 percent, a power factor of 0.70 lagging, and a load of 20 hp. Load B is a bank of overexcited single-phase synchronous machines. The machines draw 15 kVA, and the load current leads the line voltage by 30°. Load C is a lighting (resistive) load and absorbs 10 kW. Load D is a proposed single-phase capacitor that will correct the source power factor to unity. This material is covered in Sections 7.1 and 7.2.

CHECK YOUR UNDERSTANDING

H.4 The root-mean-square magnitude of load A current, denoted by I_A, is most nearly

a. 44.4 A b. 31.08 A c. 60 A d. 38.85 A e. 55.5 A

H.5 The phase angle of $\mathbf{I}_A$ with respect to the line voltage $\mathbf{E}_S$ is most nearly

a. 36.87° b. 60° c. 45.6° d. 30° e. 48°

H.6 The power absorbed by synchronous machines is most nearly

a. 20,000 W b. 7,500 W c. 13,000 W d. 12,990 W e. 15,000 W

H.7 The power factor of the system before load D is installed is most nearly

a. 0.70 lagging b. 0.866 leading c. 0.866 lagging
d. 0.966 leading e. 0.966 lagging

H.8 The capacitance of the capacitor that will give a unity power factor of the system is most nearly

a. 219 μF b. 187 μF c. 132.7 μF d. 240 μF e. 132.7 pF

Answers: **H.4:** The output power P_o of the single-phase induction motor is $P_o = 20 \times 746 = 14{,}920$ W. The input electric power P_{in} is

$$P_{\text{in}} = \frac{P_o}{\eta} = \frac{14{,}920}{0.80} = 18{,}650 \text{ W}$$

P_{in} can be expressed as

$$P_{\text{in}} = E_S I_A \cos\theta_A$$

Therefore, the rms magnitude of the current $\mathbf{I}_A$ is found as

$$I_A = \frac{P_{\text{in}}}{E_S \cos\theta_A} = \frac{18{,}650}{480 \times 0.70} = 55.5015 \approx 55.5 \text{ A}$$

Thus, the correct answer is e.
H.5: The phase angle between $\mathbf{I}_A$ and $\mathbf{E}_S$ is

$$\theta = \cos^{-1} 0.70 = 45.57^\circ \approx 45.6^\circ$$

The correct answer is c.
H.6: The apparent power S is known to be 15 kVA, and θ is 30°. From the power triangle, we have

$$P = S\cos\theta$$

Therefore, the power drawn by the bank of synchronous motors is

$$P = 15{,}000 \times \cos 30^\circ = 12{,}990.38 \approx 12.99 \text{ kW}$$

The answer is d.
H.7: From the expression for the current $\mathbf{I}_S$, we have

$$\text{pf} = \cos\theta = \cos[0^\circ - (-15^\circ)] = \cos 15^\circ = 0.966 \text{ lagging}$$

The correct answer is e.
H.8: The reactive power Q_A in load A is

$$Q_A = P_A \times \tan\theta_A$$
$$\theta_A = \cos^{-1} 0.70 = 45.57^\circ$$

Therefore,

$$Q_A = 18{,}650 \times \tan 45.57^\circ = 19{,}025 \text{ VAR}$$

The total reactive power Q_B in load B is

$$Q_B = S \times \sin\theta_B = 15{,}000 \times \sin(-30^\circ) = -7{,}500 \text{ VAR}$$

The total reactive power Q is

$$Q = Q_A + Q_B = 19{,}025 - 7{,}500 = 11{,}525 \text{ VAR}$$

To cancel this reactive power, we set

$$Q_C = -Q = -11{,}525 \text{ VAR}$$

and

$$Q_C = -\frac{E_S^2}{X_C} \qquad \text{and} \qquad X_C = -\frac{1}{\omega C}$$

Therefore, the capacitance required to obtain a power factor of unity is

$$C = -\frac{Q_C}{\omega E_S^2} = \frac{11{,}525}{120\pi \times 480^2} = 132.7\ \mu\text{F}$$

The correct answer is c.

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I. Basic complex algebra

A review of complex algebra is contained in Appendix A, Section A.2. The examples and exercises included in this section will provide the needed review material.