FINAL ANSWERS for odd-numbered problems

Magnetic Actuators and Sensors

To request complete solution descriptions for all problems, along with related software files, send an email with subject line "Solution Manual Request" to: jbrauer@ieee.org. The Solution Manual is not available to students unless authorized by their instructor.

2.1) $\nabla T = 10\mathbf{u}_x + 60y^2\mathbf{u}_y + 30\mathbf{u}_z$ degrees per meter.

2.3) $\nabla \bullet \mathbf{A} = 32(1)^3 + 10 = 42$ **,** $\nabla \times \mathbf{A} = (-11)\mathbf{u}_x + (-4)\mathbf{u}_y + (-15)\mathbf{u}_z$

2.5) $\mathbf{J} = -12\mathbf{u}_x - 4\mathbf{u}_y - 279\mathbf{u}_z$ amperes per square meter.

2.7) a) **B** = (1.2E-3 $\mathbf{u}_x$ + 1.6E-3 $\mathbf{u}_y$) teslas

b) **B** = (3 $\mathbf{u}_x$ + 4 $\mathbf{u}_y$) teslas

c) **B** = (0.93 $\mathbf{u}_x$ + 1.24 $\mathbf{u}_y$) teslas.

2.9) For aluminum conductivity changed to its correct value of 3.54E7 S/m (as in Errata),

$V = -4524\cos(2p\,60t)$ volts, $I = -1131\cos(2p\,60t)$ amperes,

$E = -514\cos(2p\,60t)$ volts/meter, $J = -18.2E9\cos(2p\,60t)$ amperes per square meter.

2.11) $\mathbf{E} = -4\mathbf{u}_y - 75.4x\cos(2p\,60t)\mathbf{u}_z$ volts/meter.

2.13) $\mathbf{J}_{disp} = 12.07E-6\cos(2p\,50t)\mathbf{u}_y$ amperes per square meter,

$I_C = 42.25E-9\cos 314.16t$ amperes.

3.1) $f = 10.93E-4$ webers, $B = 0.102$ tesla

3.3) B_{align}= 0.6285 T, $B_{misalign}$= 0.06285 T

4.1)

$$\begin{pmatrix} 1352 & 1750 & 2148 & 0 & 0 \\ 1750 & 2307 & 2864 & 0 & 0 \\ 2148 & 2864 & (3580+2.704) & 3.500 & 4.296 \\ 0 & 0 & 3.500 & 4.614 & 5.728 \\ 0 & 0 & 4.296 & 5.728 & 7.160 \end{pmatrix} \begin{bmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{bmatrix} = \begin{bmatrix} 1.333 \\ 1.333 \\ 1.333 \\ 0 \\ 0 \end{bmatrix}$$

4.3) energy stored = 137.28 J with energy error = 0.41%.

5.1) $\mathbf{B} = -1\mathbf{u}_y$

5.3) $\mathbf{B} = 2y\mathbf{u}_x$

5.5) $P_{mag} = 480984$ Pa

5.7) F_{mag} = 62.03 N

5.9) **F** = 80 $\mathbf{u}_z$ newtons per meter

5.11) The computed force on the lower magnet is 3.43 newtons upwards.

5.13) The computed force on the lower magnet is 68.45 newtons upwards.

6.1) The finite element value of flux for 0.1 meter depth is 0.00314 weber for 1 turn.

The reluctance method obtains flux = 0.00125 weber.

6.3) Proof. Evaluation gives magnetic force = -113 N, agreeing exactly with corrected result of Example 6.2.

6.5) L_{11}=L_{22}=6.06E-8 henry and L_{12}=L_{21}=1.799E-8 henry, all for one turn.

6.7) L=12.477E-4 H

6.9) Z=(-565.5+j377) ohms. Note: for realistic positive R, given λ should have negative imaginary part.

6.11) For 20 turns in the lower coil, the matrices for one turn have L_{11}=L_{22}=8.90E-8 henry, L_{12}=L_{21}=1.785E-8 henry, R_{11}=R_{22}=8.9E-8 ohm, and R_{12}=R_{21}=6.23E-8 ohm.

7.1) a) force on the left gap = 529 N in the –y direction for one meter depth.

b) same force on right gap, so total force = 1058 N per meter depth.

c) 1431 N per meter depth.

d) 1431.6 N per meter depth

e) plot shows force as high as 2200 N.

7.3) a) force = 1244 N for one meter depth.

b) force = 2391 N for one meter depth.

c) force = 2442 N for one meter depth.

7.5) 15.1 N

7.7) Plot shows total force as high as 1000 N.

8.1) Matrix for one turn has L_{11}=L_{22}=6.058E-8 henry, L_{12}=L_{21}=1.795E-8 henry, R_{11}=R_{22}=5.6E-9 ohm and R_{12}=R_{21}=4.05E-9 ohm

8.3) a) 64.97 m, b) 8.53 mm, c) 325 μm

8.5) L_p = 1.7 mH, R_p = 9.612 ohms.

8.7) force has time-average value of 8.566 N and an “AC fluctuation” of 8.528 N

8.9) power loss = 0.198 watts per meter depth.

9.1) a = 7225 m/s^2, for s = 5.E-3 m t = 1.176 ms.

9.3) a) 581.4 ms, b) energy = 0.658 J, c) 581.4 ms

9.5) a) 0.0581 ms, b) energy = 0.653 J, c) 0.0581 ms

9.7) finite element diffusion times are 28 ms and 14 ms.

10.1) a) s_o=6.4 S/m, b)

$$\begin{pmatrix} s_{xx} & s_{xy} \\ s_{yx} & s_{yy} \end{pmatrix} = \begin{pmatrix} 6.1761 & -1.1759 \\ 1.1759 & 6.1761 \end{pmatrix}$$

10.3) power loss = 5 W without Al, 5.224 W with Al.

10.5) $V_y = k_H J_x d_y (0.03143 + 0.2828 \sin n_T q)$ volts

11.1) $V = -\Omega N n_T (283E-6)\cos(n_T \Omega t)$ volts

11.3) a) $Z(.002) = 228E-5 + j664E-5$ ohms, $Z(.004) = 2055E-5 + j757E-5$ ohms

b) $Z(.002) = 318.7E-5 + j1206E-5$, $Z(.004) = 280E-5 + j1408E-5$ ohms.

c) $Z(.002) = 489E-5 + j2215E-5$, $Z(.004) = 426E-5 + j2652E-5$ ohms.

11.5) 15.55 volts.

12.1) N=826, I=1.211 amperes.

12.3) N=1077, I=0.929 amperes

12.5) R= 0.5726E-4 ohms per meter, J plot is as high as almost 350000 amperes per square meter.

12.7) P = 0.365 watts, J plot shows differing densities.

12.9) maximum temperature is 48.1 degrees C.

12.11) maximum temperature is 71.3 degrees C.

13.1) a) plot with skin depth = 0.6 mm.

b) plot shows aperture has 0.038 T inside and 0.020 T outside

c) plot with skin depth = 0.08 mm.

d) outside location has 104 mT

13.3) characteristic impedance = 67.7 ohms

13.5) characteristic impedance = 65.55 ohms

14.1) reluctance $\Re$ = 95.47, $|I_1|$ = 738.5 A, $|I_2|$ = 184.6 A

15.1) plot shows $I(t=1)$ = 0.79987 amperes

15.3) The current minimum at 0.8 s is now 0.721 amperes.

15.5) The maximum (negative) force is now 51.22 newtons.

15.7) Comparison of responses of actuator models with mass 0.06 kg.

Time-domain Specification	Third-order system Simulation results	Reduced-order Simulation results	Reduced-order Using (E15.4.2)
P.O.	14.7%	15.0%	15.04%
t_p, sec	0.745	0.704	0.7104
t_s, sec	1.56	1.52	1.5

15.9) At ω=1000 rad/s, the 2nd order magnitude is approximately -90 dB and the 3rd order magnitude is approximately -130 dB. At the same frequency, the 2nd order phase angle is close to -180 degrees and the 3rd order phase angle is close to -270 degrees. At lower frequencies the 2nd and 3rd order results are in much closer agreement.

16.1) The flow rates are 2.5E-3 m^3/s in R_1 and 1.25E-3 m^3/s in R_2.

16.3) Q=2.70 cubic meters per second

16.5) Q=2.31 cubic meters per second

16.7) At t=30 ms, the pressure is 499.755 Pa