

SULIT

UNIVERSITI MALAYSIA PERLIS

Peperiksaan Akhir Semester Pertama
Sidang Akademik 2025/2026

Januari - Februari 2026

EMJ44203 – Electrical Machine Design
[*Rekabentuk Mesin Elektrik*]

Masa : 3 jam

Please make sure that this question paper has **THIRTEEN (13)** printed pages including this front page before you start the examination.

*[Sila pastikan kertas soalan ini mengandungi **TIGA BELAS (13)** muka surat yang bercetak termasuk muka hadapan sebelum anda memulakan peperiksaan ini.]*

This question paper has **FOUR (4)** questions. Answer **ALL** questions. Each question contributes 25 marks.

*[Kertas soalan ini mengandungi **EMPAT (4)** soalan. Jawab **SEMUA** soalan. Markah bagi tiap-tiap soalan adalah 25 markah.]*

Note: Please submit **APPENDIX 4** together with the examination answer book.

*[Nota: Sila hantarkan **LAMPIRAN 4** bersama dengan buku jawapan peperiksaan.]*

Question 1*[Soalan 1]*

- (a) Sketch the B-H curve of a ferromagnetic material and label all the key characteristics of the B-H curve. Then, state **TWO (2)** different characteristics between soft and hard magnetic materials.

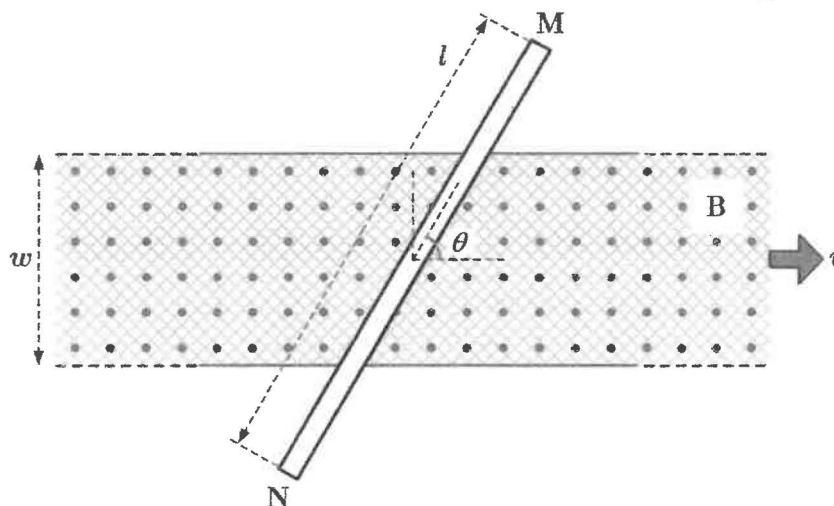
[Lakarkan lengkung B-H untuk bahan feromagnet dan labelkan semua ciri utama lengkung B-H tersebut. Seterusnya, nyatakan DUA (2) perbezaan ciri antara bahan magnet lembut dan bahan magnet keras.]

(5 Marks/ Markah)

- (b) A stationary conductor bar MN of length $l = 20$ cm is placed over a long magnetic strip, as shown in **Figure 1(a)**. The strip produces a uniformly distributed magnetic field B confined to a region of width $w = 10$ cm, and it moves from left to right at speed $v = 10$ m/s. Note that the conductor is oriented at an angle $\theta = 60^\circ$ relative to the direction of motion of the strip, and the dots in the shaded area indicate the direction of the magnetic field. Determine the magnitude of the induced voltage across the terminals MN. Recommend a suitable approach and show how it can be applied to analyze and determine the polarity of the induced voltage at terminals M and N.

[Sebuah bar konduktor pegun MN dengan panjang $l = 20$ cm diletak di atas jalur magnet panjang seperti yang ditunjukkan dalam Rajah 1(a). Jalur tersebut menghasilkan medan magnet seragam B yang terhad pada suatu kawasan dengan lebar $w = 10$ cm, dan ia bergerak dari kiri ke kanan pada kelajuan $v = 10$ m/s. Perhatikan bahawa konduktor tersebut diorientasikan pada sudut $\theta = 60^\circ$ berbanding arah pergerakan jalur tersebut, dan titik-titik dalam kawasan terteduh menunjukkan arah medan magnet. Tentukan magnitud voltan teraruh merentasi terminal MN. Cadangkan satu kaedah yang sesuai dan tunjukkan bagaimana ia boleh digunakan untuk menganalisis serta menentukan kecutuban voltan teraruh pada terminal M dan N.]

(8 Marks/ Markah)

**Figure 1(a)***[Rajah 1(a)]*

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- (c) A magnetic core made of ferromagnetic material is shown in **Figure 1(b)**. The central limb of the core has a length $L_C = 25$ cm and a cross-sectional area of 16 cm², while the airgap length is 1 mm. The two side limbs have lengths $L_L = 45$ cm and $L_R = 45$ cm, each with a cross-sectional area of 10 cm². Assuming that flux leakage and fringing effects are negligible, sketch the equivalent magnetic circuit and determine the number of ampere-turns required to produce a flux of 2 mWb in the central limb. The magnetization of the ferromagnetic material is provided in **Table 1**.

[Sebuah teras magnet yang diperbuat daripada bahan ferromagnet ditunjukkan dalam **Rajah 1(b)**. Lengan tengah teras tersebut mempunyai panjang $L_C = 25$ cm dan luas keratan rentas 16 cm², manakala panjang celah udaranya adalah 1 mm. Kedua-dua lengan sisi masing-masing mempunyai panjang $L_L = 45$ cm dan $L_R = 45$ cm, dengan setiap satunya mempunyai luas keratan rentas 10 cm². Dengan andaian kebocoran fluks dan kesan peminggiran boleh diabaikan, lakarkan litar magnet setara dan tentukan bilangan ampere-lilit yang diperlukan untuk menghasilkan fluks sebanyak 2 mWb dalam lengan tengah. Pemagnetan bahan ferromagnet tersebut diberikan dalam **Jadual 1**.]

Table 1
[**Jadual 1**]

Flux density (Wb/m ²) [Ketumpatan fluks (Wb/m ²)]	0	0.25	0.50	0.75	1.00	1.25	1.50
Magnetic field strength (AT/m) [Kekuatan medan magnet (AT/m)]	0	135	245	331	412	516	659

(12 Marks/ Markah)

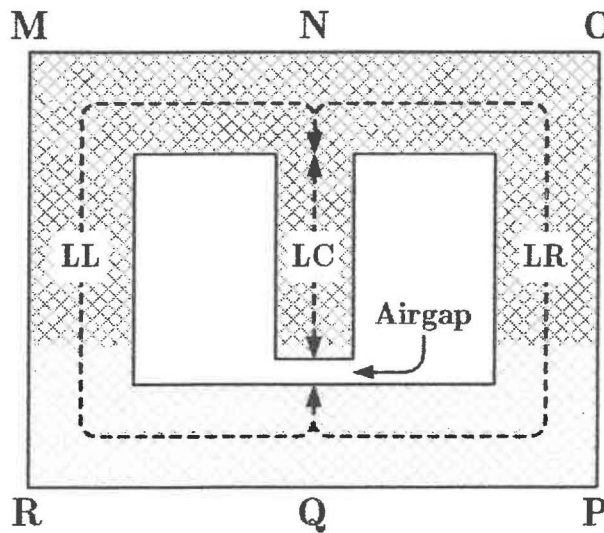


Figure 1(b)
[**Rajah 1(b)**]

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Question 2
[Soalan 2]

A client has ordered a 3-phase Delta/Delta power transformer to supply a full-bridge rectifier. The transformer specifications are provided in **Table 2**. Design a transformer that meets these specifications. Justify that the transformer can be constructed using 1.500EI-3P laminations, can achieve a minimum efficiency (η) of 92 %, and can comply with a regulation requirement of not more than 5 %. Additional technical data are provided in the appendices. State any assumptions made.

[Seorang pelanggan telah menempah sebuah pengubah kuasa 3-fasa Delta/Delta untuk membekalkan penerus titi penuh. Spesifikasi pengubah diberikan dalam **Jadual 2**. Reka bentuk pengubah yang memenuhi spesifikasi tersebut. Justifikasikan bahawa pengubah tersebut boleh dibina menggunakan laminasi 1.500EI-3P, boleh mencapai kecekapan minimum (η) sebanyak 92 %, dan boleh mematuhi keperluan regulasi tidak lebih daripada 5%. Data teknikal tambahan diberikan dalam lampiran. Nyatakan sebarang andaian yang dibuat.]

(25 Marks/ Markah)

Table 2
[Jadual 2]

Input voltage, V_{in} [Voltan masukan, V_{in}]	3-phase, 400 V, 50 Hz
Output voltage, V_{out} [Voltan keluaran, V_{out}]	48 V
Output current, I_{out} [Arus keluaran, I_{out}]	20 A
Flux density, B_{ac} [Ketumpatan fluks, B_{ac}]	1.4 T
Window utilization, K_u [Tingkat penggunaan, K_u]	0.4
Diode voltage drop, V_d [Voltan susut diod, V_d]	1.2 V
Core losses (W/kg) [Kehilangan teras (Watt/kg)]	0.7 W/kg
Regulation, α [Pengaturan, α]	5 %

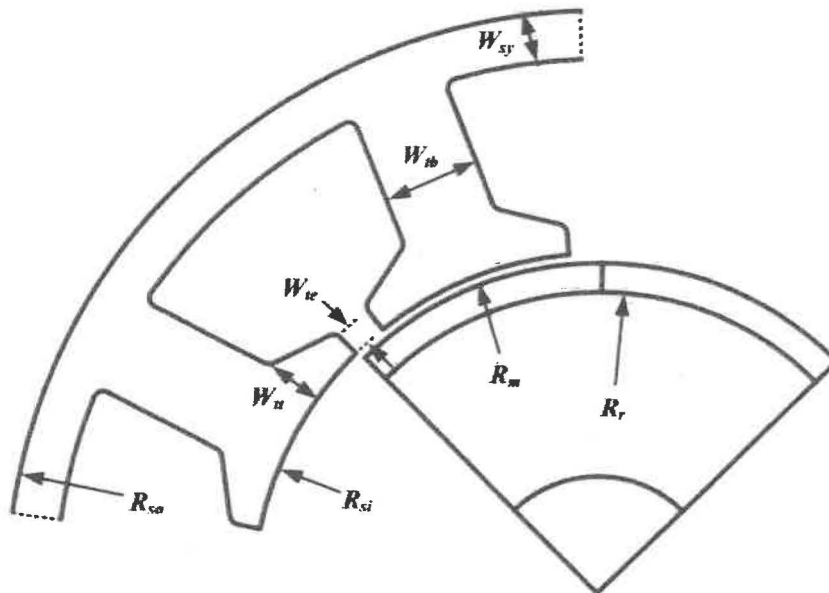
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Question 3*[Soalan 3]*

The geometric dimensions of a three-phase, 9-slot/10-pole permanent-magnet brushless motor are shown in **Figure 3**, and the corresponding parameter values are provided in **Table 3**.

[Dimensi-dimensi geometrik bagi sebuah motor magnet kekal tanpa berus tiga fasa, 9-alur/10-kutub ditunjukkan dalam Rajah 3, dan nilai parameter yang sepadan diberikan dalam Jadual 3.]

**Figure 3***[Rajah 3]*

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Table 3
[Jadual 3]

Parameter [Parameter]	Value [Nilai]
Stator & rotor active length, l_a [Panjang aktif pemegun dan pemutar, l_a]	60 mm
Stator outer radius, R_{so} [Jejari luaran pemegun, R_{so}]	50 mm
Stator inner radius, R_{si} [Jejari dalaman pemegun, R_{si}]	27 mm
Magnet thickness, h_m [Ketebalan magnet, h_m]	3 mm
Air gap thickness, l_g [Ketebalan sela udara, l_g]	1 mm
Saturation flux density in iron, B_{sat} [Ketepuan ketumpatan fluks dalam besi, B_{sat}]	1.6 T
Magnet NdFeB remanence, B_r [Baki NdFeB magnet, B_r]	1.2 T
Magnet NdFeB relative permeability, μ_r [Kebolehtelapan nisbi NdFeB magnet, μ_r]	1.05
Synchronous frequency, f [Frekuensi segerak, f]	50 Hz
Number of turns per phase, N_{tpph} [Bilangan lilitan per fasa, N_{tpph}]	128

As an electrical machines engineer, design a permanent-magnet brushless motor that fulfils the specifications listed in **Table 3**. Then, determine the appropriate winding configuration for this motor and sketch it in **APPENDIX 4**. Demonstrate that the rms value of the fundamental component of the phase back-emf does not exceed 30 V. If the motor is supplied with a sinusoidal phase current of 9 A peak at synchronous speed, justify that the motor is capable of producing at least 7 Nm of output torque.

[Sebagai seorang jurutera mesin elektrik, reka bentuk sebuah motor magnet kekal tanpa berus yang memenuhi spesifikasi dalam **Jadual 3**. Seterusnya, tentukan konfigurasi belitan yang sesuai untuk motor ini dan lakarkannya dalam **LAMPIRAN 4**. Buktikan bahawa nilai rms komponen asas daya gerak elektrik balik fasa tidak melebihi 30 V. Jika motor dibekalkan dengan arus fasa sinusoidal sebanyak 9 A puncak pada kelajuan segerak, justifikasikan kepada pelanggan bahawa motor tersebut mampu menghasilkan sekurang-kurangnya 7 Nm tork keluaran.]

(25 Marks/ Markah)

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Question 4**[Soalan 4]**

- (a) In the design of a three-phase induction motor, the output capability of the machine is influenced by both the average air-gap flux density and the specific electric loading. Explain how variations in the air-gap flux density and the specific electric loading affect the motor's ability to deliver power, and how these variations determine the overall physical size of the motor.

[Dalam mereka bentuk motor aruhan tiga fasa, keupayaan keluaran motor dipengaruhi oleh purata ketumpatan fluks sela udara dan beban elektrik khusus. Jelaskan bagaimana perubahan dalam ketumpatan fluks celah udara dan beban elektrik khusus mempengaruhi keupayaan motor menghasilkan kuasa serta bagaimana perubahan ini menentukan saiz fizikal motor.]

(6 Marks/ Markah)

- (b) As an induction motor design engineer, you are tasked with developing a 23 kW, 415 V, three-phase, four-pole, 50 Hz squirrel-cage induction motor with a delta-connected stator. The detailed design requirements specified by the client are listed in **Table 4**.

[Sebagai jurutera reka bentuk motor aruhan, anda dikehendaki mereka bentuk sebuah motor aruhan sangkar tupai tiga fasa berkuasa 23 kW, 415 V, empat kutub, 50 Hz dengan sambungan stator jenis delta. Spesifikasi reka bentuk terperinci yang diperlukan oleh pihak klien diberikan dalam Jadual 4.]

Table 4
[Jadual 4]

Specific magnetic loading, B_{av} <i>[Beban magnet tentu, B_{av}]</i>	0.47 T
Specific electric loading, q <i>[Beban elektrik tentu, q]</i>	28 000 A/m
Full load power factor <i>[Faktor kuasa beban penuh]</i>	0.84
Winding factor, K_w <i>[Faktor belitan, K_w]</i>	0.93
Full load efficiency, η <i>[Faktor kuasa beban penuh, η]</i>	87 %
Number of slot/pole/phase <i>[Nombor lubang alur/kutub/fasa]</i>	6

- (i) Using the equations provided in **Appendix 1**, assess whether the induction motor designed according to the given specifications can achieve the full-load efficiency required by the client.

[Dengan menggunakan persamaan yang diberikan dalam Lampiran 1, nilaikan sama ada motor aruhan yang direka berdasarkan spesifikasi yang diberikan dapat mencapai kecekapan beban penuh seperti yang diperlukan oleh pihak klien.]

(11 Marks/ Markah)

....8/-

- (ii) Design a second induction motor that can accommodate a 15% increase in electric loading, as specified in **Table 4**. Compare this new design with the motor developed in part **Q4(b)(i)** and evaluate the effects of the increased loading on the differences between the two designs.

[Reka bentuk sebuah lagi motor aruhan yang mampu menampung peningkatan beban elektrik sebanyak 15% seperti yang dinyatakan dalam Jadual 4. Bandingkan reka bentuk baharu ini dengan motor yang dibangunkan dalam bahagian Q4(b)(i), dan nilai kesan perubahan tersebut terhadap perbezaan antara kedua-dua reka bentuk.]

(8 Marks/ Markah)

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Appendix 1: List of equations
[Lampiran 1: Senarai persamaan]

$$B = \mu H$$

$$\phi = BA$$

$$\mu = \mu_r \mu_0$$

$$e_{ind} = -N \frac{d\phi}{dt}$$

$$e_{ind} = (\mathbf{v} \times \mathbf{B}) \cdot \mathbf{l}$$

$$e_{ind} = vBl \sin \theta_1 \cos \theta_2$$

$$\mathbf{F} = i(\mathbf{l} \times \mathbf{B})$$

$$F = ilB \sin \theta$$

$$F = HI$$

$$F = Ni$$

$$F = \phi R$$

$$R = \frac{l}{\mu A}$$

$$\alpha = \frac{P_{cu}}{P_o} \times 100$$

$$A_{wp(B)} = \frac{K_{u(p)} W_a}{4N_p}$$

$$A_{ws(B)} = \frac{K_{u(s)} W_a}{4N_s}$$

$$\eta = \frac{P_o}{P_o + P_{total_loss}} \times 100$$

$$I_{p(Line)} = \frac{P_o}{3V_{p(Line)} \eta}$$

$$I_{p(Phase)} = \frac{I_{p(Line)}}{\sqrt{3}}$$

$$I_{s(Line)} = 0.471 \times I_o$$

$$I_{s(Phase)} = \frac{I_{s(Line)}}{\sqrt{3}}$$

$$K_e = 2.86 f^2 B^2 (10^{-4})$$

$$K_g = \frac{P_t}{2K_e \alpha}$$

$$N_p = \frac{V_{p(Line)} (10^4)}{4.44 B_{ac} A_c f}$$

$$N_s = \frac{N_p V_s}{V_p} \left(1 + \frac{\alpha}{100} \right)$$

$$P_{cu} = P_p + P_s$$

$$P_{fe} = \text{Watts/Kg} \times W_{fe}$$

$$P_o = I_o (V_o + 2V_d)$$

$$P_p = 3 \left[I_{p(Phase)} \right]^2 R_p$$

$$P_s = 3 \left[I_{s(Phase)} \right]^2 R_s$$

$$P_t = P_o \left(\frac{1.05}{\eta} + 1.05 \right)$$

$$P_{total_loss} = P_p + P_s + P_{fe}$$

$$R_p = \text{MLT} (N_p) \left(\frac{\mu \Omega}{\text{cm}} \right) (10^{-6})$$

$$R_s = \text{MLT} (N_s) \left(\frac{\mu \Omega}{\text{cm}} \right) (10^{-6})$$

$$V_s = 0.740 \times (V_o + 2V_d)$$

$$B_g = \frac{B_r}{1 + \frac{\mu_r l_g}{h_m}}$$

$$\phi_{sp} = B_g \times A_{sp}$$

$$\theta_s = \frac{360^\circ}{N_s}$$

$$\theta_p = \frac{360^\circ}{N_p}$$

$$N_{app} = \frac{N_s}{N_p}$$

$$K_{pn} = \sin\left(\frac{np\pi}{N_s}\right)$$

$$K_{dn} = \frac{1}{3} \left[1 - 2 \cos\left(\frac{np2\pi}{N_s}\right) \right]$$

$$K_{wn} = K_{pn} \times K_{dn}$$

$$E_{ph_rms} = 4.44 f K_{wn} N_{ph} \phi_p$$

$$T_{em} = \frac{P_{out}}{\omega_m}$$

$$D^2 L = \frac{Q}{C_0 n_s} \text{ m}^3$$

$$C_0 = 11 B_{av} q K_w n \cos \theta \times 10^{-3}$$

$$n_s = \frac{(120 f / p)}{60}$$

$$\text{flux/pole, } \phi = \frac{\pi DL}{P} B_{av}$$

$$T_{ph} = \frac{E_{ph}}{4.44 f \phi K_w}$$

Appendix 2: Datasheet of steel lamination
[Lampiran 2: Lembaran data bagi salutan keluli]

3Phase, Standard Laminations, Thomas & Skinner 14 mil									
Part No.	W _{tcu} grams	W _{tfe} grams	MLT cm	W _a	A _c cm ²	W _a cm ²	A _p cm ⁴	K _g cm ⁵	A _t cm ²
				2A _c					
0.250EI	57	54	4.3	3.251	0.383	2.49	1.43	0.051	53
0.375EI	134	154	6.2	2.339	0.862	4.03	5.21	0.289	102
0.500EI	242	324	8.2	1.810	1.532	5.54	12.74	0.955	159
0.562EI	403	421	8.8	2.213	1.936	8.57	24.88	2.187	207
0.625EI	600	706	10.1	2.334	2.394	11.18	40.13	3.816	275
0.875EI	1255	1743	13.9	1.809	4.693	16.98	119.53	16.187	487
1.000EI	2594	2751	16.7	2.368	6.129	29.03	266.91	39.067	730
1.200EI	2178	3546	17.6	1.316	8.826	23.23	307.48	61.727	725
1.500EI	4266	6957	22.0	1.316	13.790	36.29	750.68	187.898	1132
1.800EI	7326	12017	26.3	1.316	19.858	52.26	1556.61	470.453	1630
2.400EI	17230	28634	34.8	1.316	35.303	92.90	4919.66	1997.995	2899
3.600EI	58144	96805	52.2	1.316	79.432	209.03	24905.75	15174.600	6522

Appendix 3: Wire table
[Lampiran 3: Jadual dawai]

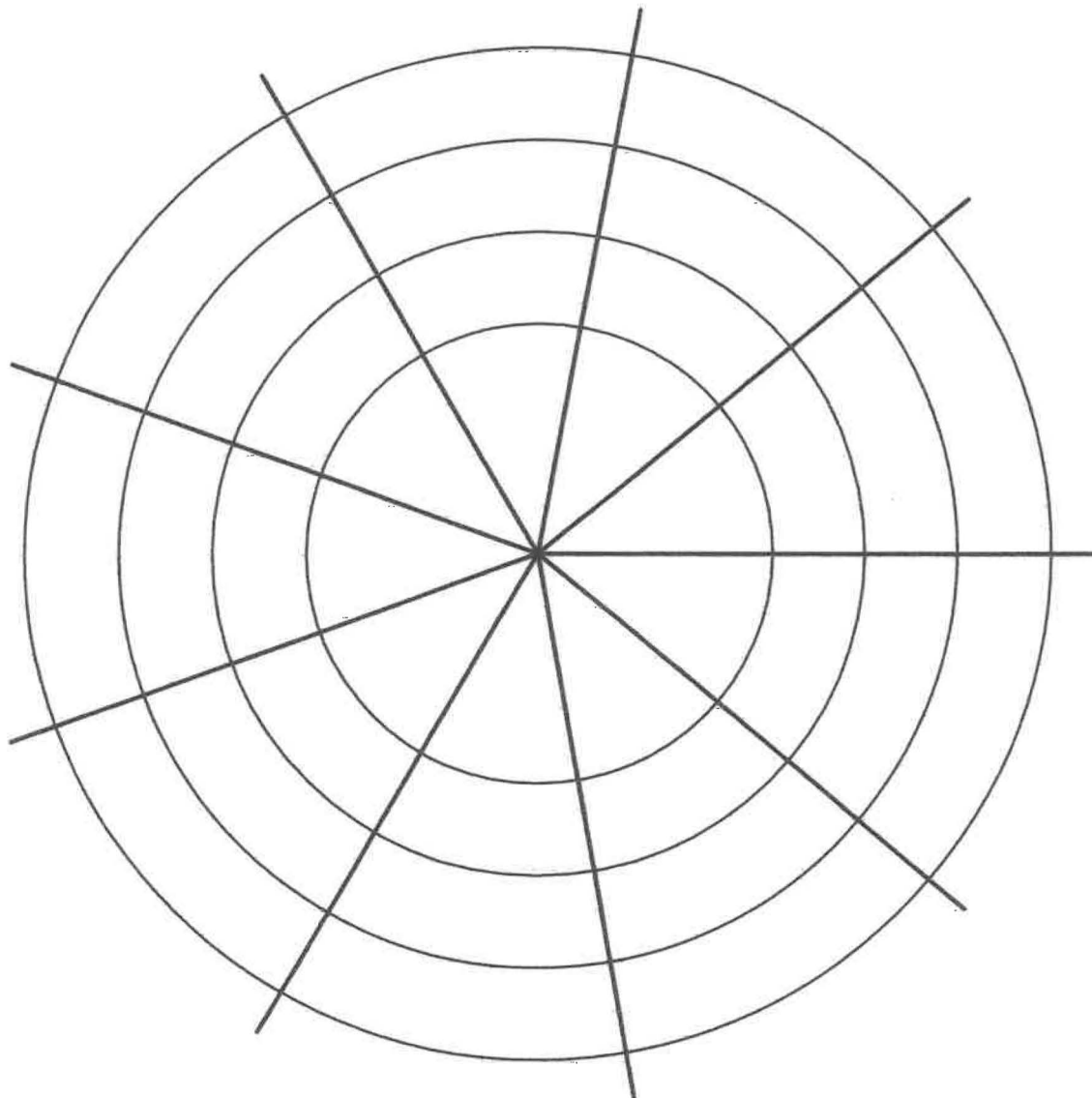
Wire Table												
AWG	Bare Area		Resistance $\mu\Omega/\text{cm}$ 20°C	Heavy Synthetics								
				Area		Diameter		Turns-Per		Turns-Per		Weight
	cm^2 (10^{-3})	cir-mil		cm^2 (10^{-3})	cir-mil	cm	Inch	cm	Inch	cm^2	Inch^2	gm/cm
1	2	3	4	5	6	7	8	9	10	11	12	13
10	52.6100	10384.00	32.7	55.9000	11046.00	0.2670	0.105	3.9	10	11	69	0.46800
11	41.6800	8226.00	41.4	44.5000	8798.00	0.2380	0.094	4.4	11	13	90	0.37500
12	33.0800	6529.00	52.1	35.6400	7022.00	0.2130	0.084	4.9	12	17	108	0.29770
13	26.2600	5184.00	65.6	28.3600	5610.00	0.1900	0.075	5.5	13	21	136	0.23670
14	20.8200	4109.00	82.8	22.9500	4556.00	0.1710	0.068	6.0	14	26	169	0.18790
15	16.5100	3260.00	104.3	18.3700	3624.00	0.1530	0.060	6.8	15	33	211	0.14920
16	13.0700	2581.00	131.8	14.7300	2905.00	0.1370	0.054	7.3	16	41	263	0.11840
17	10.3900	2052.00	165.8	11.6800	2323.00	0.1220	0.048	8.2	17	51	331	0.09430
18	8.2280	1624.00	209.5	9.3260	1857.00	0.1090	0.043	9.1	18	64	415	0.07474
19	6.5310	1289.00	263.9	7.5390	1490.00	0.0980	0.039	10.2	19	80	515	0.05940
20	5.1880	1024.00	332.3	6.0650	1197.00	0.0879	0.035	11.4	20	99	638	0.04726
21	4.1160	812.30	418.9	4.8370	954.80	0.0785	0.031	12.8	21	124	800	0.03757
22	3.2430	640.10	531.4	3.8570	761.70	0.0701	0.028	14.3	22	156	1003	0.02965
23	2.5880	510.80	666.0	3.1350	620.00	0.0632	0.025	15.8	23	191	1234	0.02372
24	2.0470	404.00	842.1	2.5140	497.30	0.0566	0.022	17.6	24	239	1539	0.01884
25	1.6230	320.40	1062.0	2.0020	396.00	0.0505	0.020	19.8	25	300	1933	0.01498
26	1.2800	252.80	1345.0	1.6030	316.80	0.0452	0.018	22.1	26	374	2414	0.01185
27	1.0210	201.60	1687.0	1.3130	259.20	0.0409	0.016	24.4	27	457	2947	0.00945
28	0.8046	158.80	2142.0	1.0515	207.30	0.0366	0.014	27.3	28	571	3680	0.00747
29	0.6470	127.70	2664.0	0.8548	169.00	0.0330	0.013	30.3	29	702	4527	0.00602
30	0.5067	100.00	3402.0	0.6785	134.50	0.0294	0.012	33.9	30	884	5703	0.00472
31	0.4013	79.21	4294.0	0.5596	110.20	0.0267	0.011	37.5	31	1072	6914	0.00372
32	0.3242	64.00	5315.0	0.4559	90.25	0.0241	0.010	41.5	32	1316	8488	0.00305
33	0.2554	50.41	6748.0	0.3662	72.25	0.0216	0.009	46.3	33	1638	10565	0.00241
34	0.2011	39.69	8572.0	0.2863	56.25	0.0191	0.008	52.5	34	2095	13512	0.00189
35	0.1589	31.36	10849.0	0.2268	44.89	0.0170	0.007	58.8	35	2645	17060	0.00150
36	0.1266	25.00	13608.0	0.1813	36.00	0.0152	0.006	62.5	36	3309	21343	0.00119
37	0.1026	20.25	16801.0	0.1538	30.25	0.0140	0.006	71.6	37	3901	25161	0.00098
38	0.0811	16.00	21266.0	0.1207	24.01	0.0124	0.005	80.4	38	4971	32062	0.00077
39	0.0621	12.25	27775.0	0.0932	18.49	0.0109	0.004	91.6	39	6437	41518	0.00059
40	0.0487	9.61	35400.0	0.0723	14.44	0.0096	0.004	103.6	40	8298	53522	0.00046
41	0.0397	7.84	43405.0	0.0584	11.56	0.0086	0.003	115.7	41	10273	66260	0.00038
42	0.0317	6.25	54429.0	0.0456	9.00	0.0076	0.003	131.2	42	13163	84901	0.00030
43	0.0245	4.84	70308.0	0.0368	7.29	0.0069	0.003	145.8	43	16291	105076	0.00023
44	0.0202	4.00	85072.0	0.0316	6.25	0.0064	0.003	157.4	44	18957	122272	0.00020

Appendix 4: Winding layout arrangement of motor
[Lampiran 4: Susun atur belitan motor]

Please attach this appendix together with the examination answer book.
[Sila lampirkan lampiran ini bersama dengan buku jawapan peperiksaan.]

Index Number
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Table Number
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