FAKULTEIT INGENIEURSWESE
FACULTY OF ENGINEERING

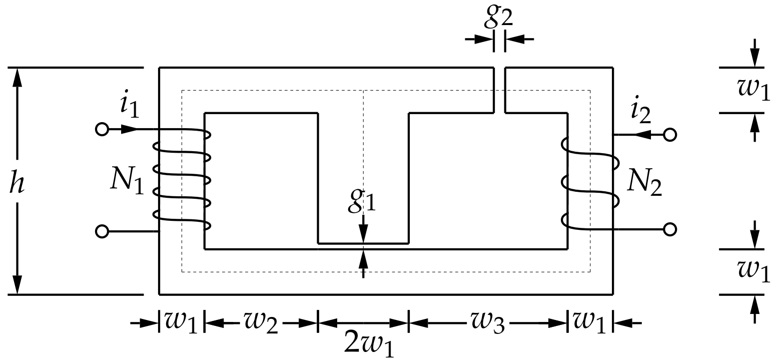
Energiestelsels 344							*Energy Systems 344*
Assesseringstoets I *Assesment Test I*	**3 September 2015** *3 September 2015*	**Tydsduur:** *Duration:*	**2h**	**Totaal:** *Total:*	**68**		

Eksaminator *Examiner*	**Interne Moderator** *Internal Moderator*
Dr. P.J. Randewijk	Prof. M.J. Kamper

Instruksies	Instructions
1. Alle berekening stappe moet duidelik getoon word.	1. All calculation steps must be shown clearly.
2. Maak deurgaans van eenvoudige sketse of ekwivalente stroombaandiagramme gebruik om u antwoorde te illustreer.	2. Continuously make use of simple sketches or equivalent circuit diagrams to illustrate all answers.
3. Die finale antwoorde moet in ink geskryf word.	3. The final answers must be written in ink.
4. Punte sal afgetrek word indien antwoorde se eenhede nie getoon word nie, b.v. 123,45 V, 123,45 mA, 123,456 kW, ens.	4. Marks will be deducted if no units for answers are shown, e.g. 123,45 V, 123,45 mA, 123,45 kW, etc.
5. Werk met ten minste vier (4) beduidende syfers, b.v. 123,4 V, 12,34 V, 1,234 V, ens.	5. Work with at least four (4) significant numbers, e.g. 123,4 V, 12,34 V, 1,234 V, etc.
6. Sakrekenaars soos voorgeskryf vir die eerste twee jaar van B.Ing. mag gebruik word.	6. Pocket calculators as prescribed for the first two years of B.Eng. may be used.
7. As daar, na u mening, enige parameters ontbreek of verkeerd is, maak redelike aannames, verklaar duidelik waarom u aannames gebruik en gaan voort.	7. If, in your opinion, there are any missing or incorrect parameters, make reasonable assumptions, stating them clearly and continue.
8. Indien daar 'n verskil tussen die "Afrikaanse" en "Engelse" gedeeltes is, stel duidelik watter taal se inligting u gebruik vir u antwoord.	8. If there is a difference between the "Afrikaans" and "English" section, state clearly which language's information you are using for your answer.
9. Geen selfone word toegelaat nie.	9. No cellphones are allowed.

Vraag 1: Magnetiese Stroombane [12]

(a) Vir die onderstaande magnetiese baan met diepte, D, en relatiewe permeabiliteit, $\mu_r \to \infty$,



i. teken die ekwivalente magnetiese stroombaan diagram in terme van $\mathcal{F}_1 = N_1 i_1$, $\mathcal{F}_2 = N_2 i_2$ en die minimum aantal reluktansies. [2]

ii. skryf die vergelyking neer vir elke reluktansie in die ekwivalente stroombaan in terme van die magnetiese baan se dimensies. [2]

iii. kry 'n vergelyking vir elke induktansie in die induktansie matriks, L_{11}, L_{12}, L_{21} en L_{22} in terme van die bogenoemde reluktansies. [8]

Wenk: Gebruik superposisie.

Question 1: Magnetic Circuits [12]

(a) For the magnetic circuit shown below with depth, D, and relative permeability, $\mu_r \to \infty$,

i. draw the equivalent magnetic circuit diagram, in terms of $\mathcal{F}_1 = N_1 i_1$, $\mathcal{F}_2 = N_2 i_2$ and the minimum number of reluctances. [2]

ii. write down the equations for each reluctance in the equivalent circuit in terms of the magnetic circuit's dimensions. [2]

iii. find an equation for each inductance in the inductance matrix, L_{11}, L_{12}, L_{21} and L_{22} in terms of the above mentioned reluctances. [8]

Tip: Use superposition.

Vraag 2: Elektromeganika [15]

(a) Deur van die energie metode gebruik te maak, kan dit verandering in die gestoorde energie van 'n konserwatiewe stelsel as volg geskryf word, [7]

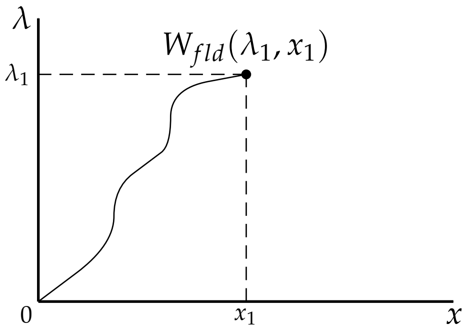
Question 2: Electromechanics [15]

(a) By making use of the energy method, the change in the stored energy of a conservative system can be written as follows, [7]

$$dW_{fld} = i d\lambda - f_{fld} dx \qquad \text{met / with} \qquad \lambda = L(x) i \, .$$

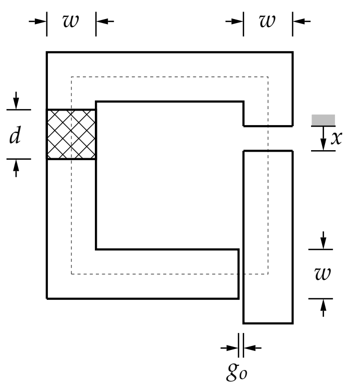
Verduidelik (met woorde en wiskunde) hoe die gestoorde energie in die stelsel, $W_{fld}(\lambda, x)$, maklik bereken kan word as 'n funksie van die toestand veranderlikes λ en x deur die integrasie pad op 'n "slim manier te kies", i.p.v. die werklike pad wat gevolg is, soos bo aan die volgende bladsy getoon.

Explain (using words and maths) how the stored energy in the system,v $W_{fld}(\lambda, x)$, can easily be calculated as a function of the state variables λ and x by choosing the integration path in an "intelligent way", instead of the actual path that was followed, as shown on top of the next page.



(b) Met die relatiewe permeabiliteit van die kern, $\mu_r \to \infty$, die terugspring permeabiliteit van die NdFeB permanente magneet, $\mu_R = -\frac{B_m}{H_c'}$, die diepte van die kern, D, en g_o 'n vaste lugspleet

(b) With the permeability of the core, $\mu_r \to \infty$, the recoil permeability of the NdFeB permanent magnet, $\mu_R = -\frac{B_m}{H_c'}$, the depth of the core, D, and g_o a fixed air-gap,



i. teken die ekwivalente magnetiese stroombaan diagram. [2]

ii. lei 'n vergelyking af vir die krag wat deur die NdFeB magneet op die bewegende kern gedeelte uitgeoefen word as 'n funksie van x. [6]

Wenk: Maak van 'n ekwivalente MMK, $(Ni)_{equiv}$, gebruik en ignoreer die fraaiings effek.

i. draw the equivalent magnetic circuit diagram. [2]

ii. find an equation for the force exerted by the NdFeB permanent magnet on the moving part of the core as a function of x. [6]

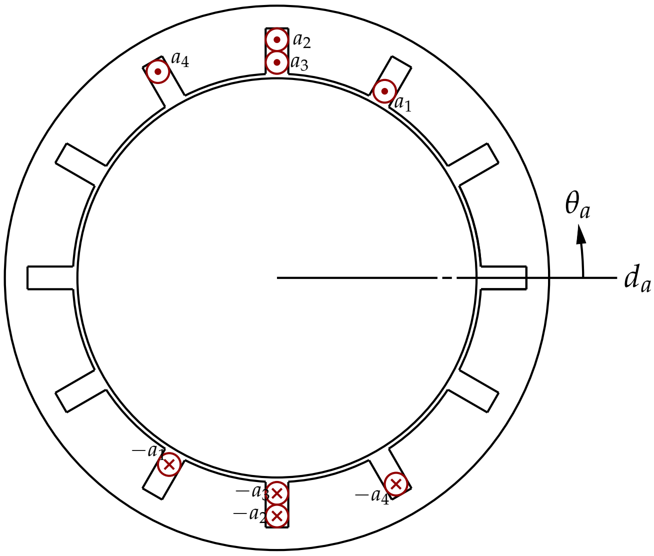
Tip: Make use of an equivalent MMF, $(Ni)_{equiv}$ and ignore the fringing effect.

Vraag 3: Roterende MMK **[24]**

Question 3: Rotating MMF **[24]**

Hierdie vraag het betrekking op die stator van 'n dubbellaag sinchroon masjien waarvan slegs die spoele van fase a op die volgende bladsy getoon word. Die hoeveelheid serie windings per fase, $N_{ph} = 4N$, met N die hoeveelheid windings in elke spoel.

This question has to do with the stator of a double layer synchronous machine with only the coils of phase a shown on top of the next page. The number of serie turns per phase, $N_{ph} = 4N$, with N the number of turns in each coil.



(a) Teken die lineêre MMK distribusie in die lugspleet van die masjien vir fase a vir enige $i_a(t)$, vanaf 0° tot 360° (*meganies*), indien ons aanvaar dat die relatiewe permeabiliteit van die stator en die rotor, $\mu_r \to \infty$. [4]

(b) Bereken die Fourier reeksuitbreiding van die MMK distribusie in die lugspleet van die masjien vir fase a, $\mathcal{F}_{ag}$, uit eerste beginsels in terme van die totale aantal serie windings per fase, N_{ph} en die fase stroom $i_a(t)$. [8]

Wenk: Maak van superposisie gebruik.

(c) Vanaf u antwoord in (b) hierbo, skryf die algemene vergelyking vir die wikkelingsfaktor, k_{w_n}, neer vir hierdie wikkelingskonfigurasie. [2]

(d) Maak van MMK ruimte-vektore gebruik om die fundamentele wikkelingsfaktor, k_{w_1}, te bereken en gebruik dit om u antwoord in (c) hierbo te bevestig. [4]

(e) Vanaf die onderste gegewens, lei 'n vergelyking af vir die fundamentele komponent van die resulterende MMK, $\mathcal{F}_{res,1}$, met die magnetiese as van fase b by 120° (*meganies*) en die magnetiese as van fase c by −120° (*meganies*): [6]

(a) Draw the linear MMF distribution in the air-gap of the machine for phase a for any $i_a(t)$, from 0° tot 360° (*mechanical*), if we assume that the relative permeability of the stator and the rotor, $\mu_r \to \infty$. [4]

(b) Calculated the Fourier series expansion of the MMF distribution in the air-gap of the machine for phase a, $\mathcal{F}_{ag}$, from first principles in terms of number of series turns per phase, N_{ph} and the phase current, $i_a(t)$. [8]

Tip: Make use of superposition.

(c) From your answer in (b) above, write down the general equation for the winding factor, k_{w_n}, for this winding configuration. [2]

(d) Make use of MMF space-vectors to calculated the fundamental winding factor, k_{w_1} and use it to check your answer in (c) above. [4]

(e) From the information given below, deduce an equation for the fundamental component of the resultant MMF, $\mathcal{F}_{res,1}$, with the magnetic axis of phase b at 120° (*mechanical*) and the magnetic axis of phase c at −120° (*mechanical*): [6]

$$
\begin{aligned}
\mathcal{F}_{ag_1} &= \frac{4}{\pi}\frac{k_{w_1}N_{ph}}{2} i_a(t)\cos(\theta_a) \\
\mathcal{F}_{bg_1} &= \frac{4}{\pi}\frac{k_{w_1}N_{ph}}{2} i_b(t)\cos(\theta_b) \\
\mathcal{F}_{cg_1} &= \frac{4}{\pi}\frac{k_{w_1}N_{ph}}{2} i_c(t)\cos(\theta_c) \\
i_a(t) &= I_{max}\cos(\omega_e t)\ \text{A} \\
i_b(t) &= I_{max}\cos(\omega_e t + 120^\circ)\ \text{A} \\
i_c(t) &= I_{max}\cos(\omega_e t - 120^\circ)\ \text{A}
\end{aligned}
$$

Vraag 4: GS-Masjiene [17]

(a) Verduidelik aan die hand van 'n eenvoudige skets, wat ankerreaksie is en hoe dit die kommutasie beïnvloed. [3]

(b) Verduidelik, deur onder andere van die B–H kromme gebruik te maak, hoe dit moontlik is dat 'n newesluitings GS-generator 'n spanning kan opwek. [2]

(c) Die veilige T_m–ω_m bedryfsarea van 'n afsonderlik gemagnetiseerde GS motor kan opgedeel word in 'n konstante draaimoment gebied en 'n konstante drywingsgebied.

i. Teken die T_m–ω_m bedryfsarea van die konstante draaimomentgebied en toon aan en verduidelik die waardes (simbolies) wat die bedryfsgrens definieer. [2]

ii. Teken die T_m–ω_m bedryfsarea van die konstante drywingsgebied op skets (i) hierbo, en toon aan en verduidelik die waardes (simbolies) wat die bedryfsgrens in hierdie gebied definieer. [2]

iii. met die veldklemspanning konstant, lei 'n vergelyking af vir die ontwikkelde draaimoment as 'n funksie van spoed (ω_m) vir die afsonderlik gemagnetiseerde GS-motor en stip die tipiese ken-lyne van die ontwikkelde draaimoment vir (sê) drie verskillende **ankerklemspanningswaardes** op die veilige bedryfsarea van (i) en/of (ii) hierbo. [4]

(d) Die veilige P_m–ω_m bedryfsarea van 'n afsonderlik gemagnetiseerde GS motor word ook opgedeel in 'n konstante draaimoment gebied en 'n konstante drywingsgebied.

i. Teken die P_m–ω_m bedryfsarea van die konstante draaimomentgebied en toon aan en verduidelik die waardes (simbolies) wat die bedryfsgrens definieer. [2]

ii. Teken die P_m–ω_m bedryfsarea van die konstante drywingsgebied op (i) hierbo, en toon aan en verduidelik die waardes (simbolies) wat die bedryfsgrens in hierdie gebied definieer. [2]

Question 4: DC Machines [17]

(a) Explain with the aid of a few simple sketches, what armature reaction is and how it affects commutation. [3]

(b) Explain, making use of amongst other the B–H curve, how it is possible for a shunt connected DC generator to generate a voltage. [2]

(c) The safe T_m–ω_m operating area of a separately excited DC motor can be divided into a constant torque region and the constant power region.

i. Sketch the T_m–ω_m operating area of the constant torque region and indicate and explain the values (symbolically) that define the operating boundary. [2]

ii. Sketch the T_m–ω_m operating area of the constant power region on sketch (i) above, and indicate and explain the values (symbolically) that define the operating boundary. [2]

iii. with the field terminal voltage constant, derive an equation for the developed torque as a function of speed (ω_m) of the separately excited DC-motor and plot the typical characteristic curves of the developed torque for (say) three different **armature terminal voltage values** on the safe operating area of (i) and/or (ii) above. [4]

(d) The safe P_m–ω_m operating area of a separately excited DC motor can also be divided into a constant torque region and the constant power region.

i. Sketch the P_m–ω_m operating area of the constant torque region and indicate and explain the values (symbolically) that define the operating boundary. [2]

ii. Sketch the P_m–ω_m operating area of the constant power region on (i) above, and indicate and explain the values (symbolically) that define the operating boundary. [2]

Formules *Formulas*

$$\sin(\alpha+\beta) = \sin\alpha\cos\beta + \cos\alpha\sin\beta$$
$$\sin(\alpha-\beta) = \sin\alpha\cos\beta - \cos\alpha\sin\beta$$
$$\cos(\alpha+\beta) = \cos\alpha\cos\beta - \sin\alpha\sin\beta$$
$$\cos(\alpha-\beta) = \cos\alpha\cos\beta + \sin\alpha\sin\beta$$

$$(fg)' = f'g + fg'$$
$$\left(\frac{1}{g}\right)' = -\frac{g'}{g^2}$$
$$\left(\frac{f}{g}\right)' = \frac{f'g - fg'}{g^2}$$

$$f(\theta_a) = a_v + \sum_{n=1}^{\infty}\big(a_n\cos(np\theta_a) + b_n\sin(np\theta_a)\big)d\theta_a$$
$$a_n = \tfrac{4p}{\pi}\int_0^{\frac{\pi}{2p}} f(\theta_a)\cos(np\theta_a)d\theta_a$$
$$b_n = \tfrac{4p}{\pi}\int_0^{\frac{\pi}{2p}} f(\theta_a)\sin(np\theta_a)d\theta_a$$

$$\oint_S \mathbf{B}\cdot d\mathbf{a} = 0$$
$$\int_S \mathbf{B}\cdot d\mathbf{a} = \phi$$
$$\oint_C \mathbf{H}\cdot d\mathbf{l} = Ni = \mathcal{F}$$

$$\mathbf{B} = \mu\mathbf{H}$$

$$\mathcal{F} = \phi\mathcal{R}$$
$$\mathcal{R} = \frac{\ell}{\mu A}$$

$$\mu = \mu_0\mu_r$$
$$\mu_0 = 4\pi\times 10^{-7}\ \mathrm{H/m}$$

$$B_m = \mu_R(H_m - H_c') = B_r + \mu_R H$$
$$\mu_R = \frac{B_r}{H_c'}$$
$$(Ni)_{equiv} = -H_c' d$$
$$\mathcal{R}_{equiv} = \frac{d}{\mu_R A_m}$$

$$L = \frac{N^2}{\mathcal{R}}$$

$$\lambda = N\phi$$
$$L = \frac{\lambda}{i}$$
$$e = \frac{d\lambda}{dt}$$

$$\begin{bmatrix}\lambda_1\\ \lambda_2\end{bmatrix} = \begin{bmatrix}L_{11} & L_{12}\\ L_{21} & L_{22}\end{bmatrix}\begin{bmatrix}i_1\\ i_2\end{bmatrix}$$

$$W_{fld}(\lambda,\theta_m) = \frac{1}{2}\frac{\lambda^2}{L(\theta_m)}$$
$$T_{fld} = \left.\frac{\partial W_{fld}(\lambda,\theta_m)}{\partial\theta_m}\right|_{\lambda}$$

$$W'_{fld}(i,\theta_m) = \frac{1}{2}L(\theta_m)i^2$$
$$T_{fld} = \left.\frac{\partial W'_{fld}(i,\theta_m)}{\partial\theta_m}\right|_{i}$$

$$\mathcal{F}_{ag}(\theta_{ae}) = \tfrac{4}{\pi}\left(\tfrac{N_{\mathrm{ph}}i_a(t)}{2p}\right)\sum_{n=1,3,5,\ldots}^{\infty}\frac{\sin\left(n\frac{\pi}{2}\right)}{n}k_{w_n}\cos(n\theta_{ae})$$

$$\theta_{me} = p\theta_m$$
$$\omega_e = p\omega_m$$
$$\omega_m = \frac{2\pi}{60}n_m$$
$$p = \frac{\text{poles}}{2}$$

$$n_m = \frac{60 f_e}{p}$$

$$E_a = K_a\phi_d\omega_m$$
$$T_m = K_a\phi_d I_a$$

$$T_b = b\omega_m$$
$$T_J = J\frac{d\omega_m}{dt}$$

$$\eta = \frac{P_{out}}{P_{in}}\times 100\%$$