Instructions:

2. Work each problem on the exam booklet in the space provided.
3. Write neatly and clearly for partial credit. Cross out any material you do not want graded.

Name: ____________________________

Problem 1: ____________________________/20
Problem 2: ____________________________/30
Problem 3: ____________________________/25
Problem 4: ____________________________/25
Total: ____________________________/100

Singly-Excited Magnetic Structure: \( W_m + W'_m = \lambda i \).

\[
W_m = W_m(\lambda, x) = \int_0^\lambda i(\lambda', x) \, d\lambda' \quad W'_m = W'_m(i, x) = \int_0^i \lambda(i', x) \, di'
\]

\[
F_e = F_e(\lambda, x) = -\frac{\partial W_m(\lambda, x)}{\partial x} \quad F_e = F_e(i, x) = \frac{\partial W'_m(i, x)}{\partial x}
\]

\[
i = i(\lambda, x) = \frac{\partial W_m(\lambda, x)}{\partial \lambda} \quad \lambda = \lambda(i, x) = \frac{\partial W'_m(i, x)}{\partial i}
\]

Doubly-Excited Magnetic Structure: \( W_m + W'_m = \lambda_1 i_1 + \lambda_2 i_2 \).

\[
W'_m = W'_m(i_1, i_2, x) = \int_0^{i_1} \lambda_1(i'_1, 0, x) \, di'_1 + \int_0^{i_2} \lambda_2(i_1, i'_2, x) \, di'_2
\]

\[
F_e = F_e(i_1, i_2, x) = \frac{\partial W'_m}{\partial x}
\]
Problem 1 (20 Points)

A 48-kVA, 2400/120-V, 60-Hz single-phase transformer is modeled by a series impedance and assumes the core losses are negligible. A sloppy engineer-in-training records the following results of a short-circuit test:

\[
V = 120 \text{ V} \\
I = 20 \text{ A} \\
P = 672 \text{ W}
\]

(You may assume that rated currents flow in the primary and secondary windings during the short-circuit test.)

(a) Check the correct answer below:

(i) The primary winding is shorted during this test.
(ii) The secondary winding is shorted during this test.

(b) Find \( R_{eH} \) and \( X_{eH} \) where the subscript \( H \) refers to the high-voltage side.
Problem 2 (30 Points)

A 1-kVA, 60-Hz, 400/100-V transformer delivers rated load at rated secondary voltage (low-voltage side) and 0.8 pf lagging. This transformer has the following parameters:

<table>
<thead>
<tr>
<th>$R_1$ (Ω)</th>
<th>$X_1$ (Ω)</th>
<th>$R_2$ (Ω)</th>
<th>$X_2$ (Ω)</th>
<th>$R_{c1}$ (Ω)</th>
<th>$X_{m1}$ (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.80</td>
<td>8.0</td>
<td>0.050</td>
<td>0.50</td>
<td>8000</td>
<td>8000</td>
</tr>
</tbody>
</table>

(a) Find $R_{e1}$ and $X_{e1}$.

(b) Find $\tilde{S}_2$, $\tilde{V}_2$, $\tilde{V}_2'$, $\tilde{I}_2$, $\tilde{I}_2'$, and $\tilde{V}_1$.

(c) Compute the efficiency $\eta$ of this transformer in percent.
Problem 3 (25 Points)

A U-shaped electromagnet is used to lift an iron bar at a distance \( x = 1 \) mm. The cross-sectional area of each pole face is \( A = wd = 12\pi \) cm\(^2\). (Assume that the permeability of the magnetic materials is infinite and neglect fringing and leakage effects.)

(a) Express the inductance \( L = L(x) \) of this magnetic structure in terms of \( \mu_0, A, N, \) and \( x \).

(b) Show that the magnetic force \( F_e = F_e(\lambda, x) \) can be expressed as

\[
F_e = F_e(\lambda, x) = -\frac{\lambda^2}{\mu_0 AN^2}
\]

(b) Compute \( |F_e| \) (N) numerically if the magnetic flux density \( B_a = 0.8 \) T in the air gap.
**Problem 4** (25 Points)

A doubly-excited rotating machine has one stator winding and one rotor winding characterized by the following flux-current relationships:

\[
\lambda_s = (0.75 + 0.25 \cos 2\theta)i_s + (0.8 \cos \theta)i_r
\]

\[
\lambda_r = (0.8 \cos \theta)i_s + (0.45 + 0.15 \cos 2\theta)i_r
\]

(a) Is this system electrically linear? **Yes**  **No**  (Underline the correct answer.)

(b) Find the magnetic coenergy of the system \(W'_m = W'_m(i_s, i_r, \theta)\).

(c) Find the electromagnetic torque \(T_e = T_e(i_s, i_r, \theta)\).

(d) Find the electromagnetic torque value for \(i_s = i_r = 1\) A and \(\theta = 90^\circ\).