Single-phase Transistor Lab Report

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Abstract

This lab intended to train the experimental skills of the experimenters and help them understand the characteristics of a single-phase transformer in no load condition and short circuit condition respectively. Related calculation and analysis based on their values of excitation parameters derived from the experimental results. There is a slight error of the experimental results, for example the transformation ratio. Possible causes included both accidental error and systematical error. It is suggested that high-quality apparatus should be applied in the lab. Also, the accuracy of the apparatus is suggested that they should be improved.
# Contents

Abstract

Contents

1 **Introduction**
   1.1 Background and Objective ........................................ 1
   1.2 Apparatus ......................................................... 1

2 **Methodology**
   2.1 Theory ........................................................... 2
      2.1.1 Transistor Working Principle ............................. 2
      2.1.2 Shell Type Transistor Feature ........................... 3
   2.2 Procedure ..................................................... 4
      2.2.1 No load test ............................................... 4
      2.2.2 Short circuit test ....................................... 5

3 **Result**
   3.1 Experimental Results .......................................... 6
      3.1.1 No load test .............................................. 6
      3.1.2 Short circuit test ...................................... 9

4 **Discussion**
   4.1 Error Analysis and Result Explanation ........................ 12

5 **Conclusion**
   5.1 Achievement .................................................... 15
   5.2 Limitation ...................................................... 15
   5.3 Suggestion ...................................................... 15

A **Pre-lab Question**

ii
Section 1

Introduction

1.1 Background and Objective

Transformer, an electrical device that can transfer energy between circuits through electromagnetic induction, are widely utilized in electrical engineering domain to increase/decrease the voltages of circuits. This component is essential for electronic-related major students to understand.

While this lab required us to measure the transformation ratio and parameters of a single-phase transformer. The working characteristics of a shell-type transistor in no-load circuiting condition and short circuit condition are also expected to be tested and understood.

1.2 Apparatus

<table>
<thead>
<tr>
<th>Table 1.1: Apparatus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Apparatus</strong></td>
</tr>
<tr>
<td>AC analog Voltmeter</td>
</tr>
<tr>
<td>AC analog Ammeter</td>
</tr>
<tr>
<td>Intelligent P/cosφ meter</td>
</tr>
<tr>
<td>Shell-type transformer</td>
</tr>
</tbody>
</table>
Section 2

Methodology

2.1 Theory

2.1.1 Transistor Working Principle

The conceptual graph of a transistor got from the lecture slides is presented below.

![Transistor diagram](image)

For a single-phase transistor, when a sinusoidal alternating current voltage $U_1$ is applied on the two ends of the primary coil, an alternating current $I_1$ is induced and an alternating magnetic flux $\phi_1$ is also generated correspondingly which forms a closed magnet circuit along the primary coil and secondary coil.

Simultaneously, a mutually induced electronic potential $U_2$ is generated, and a voltage $E_1$ with an opposite direction with that of the applied $U_1$ is also introduced in the primary coil due to the self-induction of the $\phi_1$. This $E_1$ thereby limits the intensity of the $U_1$.

**No-load current:** Even with any external load, due to the power consumption to maintain the existence of the magnetic flux $\phi_1$ and also due to the transformer loss itself to some extent, there is still a current in the primary coil to some degree, which is called the “no-load current”.

2
2.1.2 Shell Type Transistor Feature

The conceptual graphs of core type transistor and shell type transistor obtained from the lecture slides are presented below.

Core form

Shell form

For the two primary types of transistor, core type transistor is comparatively simpler than the shell type transistor. The shell type transistor possesses more solid structure compared with that of the core type transistor with more complicated manufacturing requirements. However, due to the smaller distance between the high-voltage winding and the core iron column, the insulation procession of the sell type transistor is more difficult to conducted perfectly.

Shell structure is regarded to be able to provide more reliable mechanical support for the windings, and can enable it to bear a larger electromagnetic force, thus the shell type transistor is typically suitable for those circuits that with a large current going through.
2.2 Procedure

2.2.1 No load test

• 1) Preparation: set up apparatus
  – The measuring ranges of apparatus were set to the ranges that contain the highest possible magnitudes of the corresponding measure parameters respectively.
  – The voltage output was initialized as 0 by rotating the rotary knob counterclockwise behind the machine.

• 2) Circuiting: construct the circuit for no-load test
  – As shown in figure 2.3, the high-voltage side of the transistor (A-X) was set to be open circuit and was connected to the voltmeter \( V_2 \), while the low-voltage side of the transistor (a-x) was connected within the circuit as the primary side.
  – Then, the intelligent wattmeter was connected into the circuit by connecting its ammeter and voltmeter reasonably respectively: the voltmeter was connected in parallelled with the measured segment while the ammeter was connected in series with the measured segment.

![Figure 2.3: No load test](image)

• 3) Measurement: conduct concrete measurements as required
  – After checking the correctness of the circuit connection, the "Start" button on the apparatus was pressed and the power supply was turned on
  – \( U_0 \) was changed from \( 0.3U_N \) to \( 1.2U_N \) when \( U_N \) was set as 55V, and each group of measured experimental results of parameters were recorded.
2.2.2 Short circuit test

- **1) Preparation: set up apparatus**
  
  This step was exactly the same as what we did for no load test previously.

- **2) Circuitting: construct the circuit for no-load test**
  
  - As shown in figure 2.4, the low-voltage side of the transistor (a-x) was set to be short circuit and was connected to an additional ammeter, while the high-voltage side of the transistor (A-X) was connected within the circuit as the primary side.
  
  - Then, the intelligent wattmeter was connected into the circuit by connecting its ammeter and voltmeter reasonably respectively: the voltmeter was connected in parallelled with the measured segment while the ammeter was connected in series with the measured segment.

![Figure 2.4: Short circuit test](image)

- **3) Measurement: conduct concrete measurements as required**
  
  - After checking the correctness of the circuit connection, the "Start" button on the apparatus was pressed and the power supply was turned on
  
  - $I_k$ was changed from $0.2I_N$ to $1.1I_N$ when $I_N$ was set as 0.35A, and each group of measured experimental results of parameters were recorded.

- **Attention:**
  
  - In this test, the data should be read and recorded as quickly as possible to limit the heating effect of high current in short circuit condition of the circuit.
Section 3

Result

3.1 Experimental Results

3.1.1 No load test

Experimental Results

The measured results of several sets of no load condition transistor characteristics parameters are presented in Table 3.1.

<table>
<thead>
<tr>
<th>No.</th>
<th>$U_0$ (V)</th>
<th>$I_0$ (A)</th>
<th>$P_0$ (W)</th>
<th>$U_{AX}$ (V)</th>
<th>$\cos \phi_0$</th>
<th>$U_{AX}/U_{ax}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>66.1</td>
<td>0.104</td>
<td>2.1</td>
<td>258</td>
<td>0.305</td>
<td>3.909</td>
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<tr>
<td>2</td>
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<td>1.7</td>
<td>245</td>
<td>0.349</td>
<td>3.926</td>
</tr>
<tr>
<td>3</td>
<td>58.4</td>
<td>0.058</td>
<td>1.5</td>
<td>227</td>
<td>0.443</td>
<td>3.887</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
<td>0.046</td>
<td>1.3</td>
<td>213</td>
<td>0.513</td>
<td>3.915</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>0.036</td>
<td>1.1</td>
<td>196</td>
<td>0.611</td>
<td>3.92</td>
</tr>
<tr>
<td>6</td>
<td>46.4</td>
<td>0.031</td>
<td>0.9</td>
<td>180</td>
<td>0.626</td>
<td>3.879</td>
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<td>7</td>
<td>42.3</td>
<td>0.026</td>
<td>0.7</td>
<td>165</td>
<td>0.636</td>
<td>3.900</td>
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<tr>
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<td>0.024</td>
<td>0.6</td>
<td>148</td>
<td>0.65</td>
<td>3.874</td>
</tr>
<tr>
<td>9</td>
<td>34.5</td>
<td>0.021</td>
<td>0.5</td>
<td>135</td>
<td>0.690</td>
<td>3.913</td>
</tr>
<tr>
<td>10</td>
<td>30.3</td>
<td>0.020</td>
<td>0.5</td>
<td>117</td>
<td>0.825</td>
<td>3.861</td>
</tr>
<tr>
<td>11</td>
<td>26.1</td>
<td>0.016</td>
<td>0.3</td>
<td>102</td>
<td>0.718</td>
<td>3.861</td>
</tr>
<tr>
<td>12</td>
<td>22</td>
<td>0.014</td>
<td>0.2</td>
<td>86</td>
<td>0.65</td>
<td>3.909</td>
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<tr>
<td>13</td>
<td>17.8</td>
<td>0.012</td>
<td>0.1</td>
<td>70</td>
<td>0.468</td>
<td>3.932</td>
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<tr>
<td>14</td>
<td>17.1</td>
<td>0.011</td>
<td>0.1</td>
<td>67</td>
<td>0.531</td>
<td>3.918</td>
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<tr>
<td>15</td>
<td>16.5</td>
<td>0.011</td>
<td>0.1</td>
<td>65</td>
<td>0.551</td>
<td>3.939</td>
</tr>
</tbody>
</table>
Transformation Ratio

The ratio was calculated using the last two columns of the obtained experimental data and the equation below

$$K = \frac{U_{AX}}{U_{ax}}$$ (3.1)

Substituting the experimental data, we obtained the ratio:


$$= 3.903$$ (3.3)

No load characteristics graph

The relationship between the $U_0$ and $I_0$ is presented in Figure 3.1.

![Figure 3.1: $U_0 = f(I_0)$](image)

The relationship between the $P_0$ and $U_0$ is presented in Figure 3.2.

![Figure 3.2: $P_0 = f(U_0)$](image)
The relationship between the $\cos \phi_0$ and $U_0$ is presented in Figure 3.3.

![Figure 3.3: $\cos \phi_0 = f(U_0)$](image)

**Excitation Parameter**

The three excitation parameters when $P_0$, $U_0$ and $I_0$ all refers to the situation where $U_0 = U_N$, $I_0 = 0.046A$ and $P_0 = 1.3W$ were calculated using these three formulas:

$$r_m = \frac{P_0}{I_0^2} = \frac{1.3}{0.046^2} = 614\Omega$$ (3.5)

$$Z_m = \frac{U_0}{I_0} = \frac{55}{0.046} = 1195.65\Omega$$ (3.6)

$$X_m = \sqrt{Z_m^2 - r_m^2} = \sqrt{1195.65^2 - 614^2} = 1025.95\Omega$$ (3.7)
3.1.2 Short circuit test

The measured results of several sets of short circuit condition transistor characteristics parameters are presented in Table 3.2.

<table>
<thead>
<tr>
<th>No.</th>
<th>$U_k (V)$</th>
<th>$I_k (A)$</th>
<th>$P_k (W)$</th>
<th>$I_{short} (A)$</th>
<th>$\cos \phi_k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.4</td>
<td>0.385</td>
<td>4.4</td>
<td>1.5</td>
<td>0.922</td>
</tr>
<tr>
<td>2</td>
<td>11.2</td>
<td>0.35</td>
<td>3.6</td>
<td>1.4</td>
<td>0.918</td>
</tr>
<tr>
<td>3</td>
<td>10.8</td>
<td>0.335</td>
<td>3.4</td>
<td>1.3</td>
<td>0.940</td>
</tr>
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<td>4</td>
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<td>0.310</td>
<td>2.9</td>
<td>1.2</td>
<td>0.935</td>
</tr>
<tr>
<td>5</td>
<td>9.3</td>
<td>0.285</td>
<td>2.4</td>
<td>1.1</td>
<td>0.905</td>
</tr>
<tr>
<td>6</td>
<td>8.3</td>
<td>0.260</td>
<td>2.0</td>
<td>1.0</td>
<td>0.927</td>
</tr>
<tr>
<td>7</td>
<td>7.6</td>
<td>0.235</td>
<td>1.6</td>
<td>0.94</td>
<td>0.896</td>
</tr>
<tr>
<td>8</td>
<td>6.7</td>
<td>0.210</td>
<td>1.3</td>
<td>0.81</td>
<td>0.924</td>
</tr>
<tr>
<td>9</td>
<td>5.9</td>
<td>0.185</td>
<td>1.0</td>
<td>0.72</td>
<td>0.916</td>
</tr>
<tr>
<td>10</td>
<td>5.1</td>
<td>0.160</td>
<td>0.7</td>
<td>0.63</td>
<td>0.858</td>
</tr>
<tr>
<td>11</td>
<td>4.3</td>
<td>0.135</td>
<td>0.5</td>
<td>0.53</td>
<td>0.861</td>
</tr>
<tr>
<td>12</td>
<td>3.5</td>
<td>0.110</td>
<td>0.3</td>
<td>0.44</td>
<td>0.779</td>
</tr>
<tr>
<td>13</td>
<td>2.7</td>
<td>0.088</td>
<td>0.2</td>
<td>0.34</td>
<td>0.841</td>
</tr>
<tr>
<td>14</td>
<td>2.6</td>
<td>0.08</td>
<td>0.1</td>
<td>0.32</td>
<td>0.781</td>
</tr>
<tr>
<td>15</td>
<td>2.2</td>
<td>0.07</td>
<td>0.1</td>
<td>0.28</td>
<td>0.649</td>
</tr>
</tbody>
</table>

Short circuit characteristics graph

The relationship between the $U_k$ and $I_k$ is presented in Figure 3.4.

Figure 3.4: $U_k = f(I_k)$
The relationship between the $P_k$ and $I_k$ is presented in Figure 3.5.

![Figure 3.5: $P_k = f(I_k)$](image)

The relationship between the $cos\phi_k$ and $I_k$ is presented in Figure 3.6.

![Figure 3.6: $cos\phi_k = f(I_k)$](image)
Excitation Parameter

The three excitation parameters when \( P_k, U_k \) and \( I_k \) all refers to the situation where \( I_k = I_N = 0.35A, U_k = 11.2, P_0 = 3.6W \) and \( I_{\text{short}} = 1.4 \) were calculated using these three formulas:

\[
r_k = \frac{P_k}{I_k^2} = \frac{3.6}{0.35^2} = 29.39\Omega \quad (3.8)
\]

\[
Z_k = \frac{U_k}{I_k} = \frac{11.2}{0.35} = 32\Omega \quad (3.9)
\]

\[
X_k = \sqrt{Z_k^2 - r_k^2} = \sqrt{32^2 - 29.39^2} = 12.66\Omega \quad (3.10)
\]

The equivalent parameter in the Low-voltage side when temperature is \( K=3.918 \):

\[
r_k = \frac{r_k}{K^2} = \frac{29.39}{3.918^2} = 1.915\Omega \quad (3.11)
\]

\[
Z_k = \frac{Z_k}{K^2} = \frac{32}{3.918} = 2.085\Omega \quad (3.12)
\]

\[
X_k = \frac{X_k}{K^2} = \frac{12.66}{3.918} = 0.825\Omega \quad (3.13)
\]

\[
r_{K,75^\circ C} = r_{K,\theta} = \frac{234.5 + 75}{234.5 + \theta} = \frac{29.39}{3.918} = 2.28\Omega \quad (3.14)
\]

It is known that the actual value of \( r_K \) changes with temperature, and in this case only the parameters in certain temperature were calculated, which was \( 75^\circ C \). Also, the corresponding short circuit loss \( P_{KN} \) in this situation was worked out. Here, \( \theta = 25^\circ C \).

\[
P_{KN} = I_N^2 r_{K,75^\circ C} = 0.35^2(2.28) = 0.279W \quad (3.15)
\]
4.1 Error Analysis and Result Explanation

Transformation Ratio

Theoretical Result of the transform ratio is $\frac{220}{55} = 4$, while the calculated experimental value of it is 3.903. Therefore, there is a error percentage of 2.4%.

The possible causes of this error might be that when the external voltage had very significant change, the measuring range of voltmeter might not have been changed to the most proper one in time.

Also, another definite cause of this error is that the reading of the pointer plates that displaying the magnitudes of those measured parameters could not have been 100% correct since there is always some error in terms of the reading estimation to some extent.

No load characteristics

For the $U_0 = f(I_0)$ relation, as shown in Figure 3.1, when $I_0$ increases, the $U_0$ increases as well accordingly. However, due to the fact that the magnetic is not growing linearly, and that the edge of the magnetic flux has leakage to some slight extent, the real curve is not exactly linear.

For the $P_0 = f(U_0)$ relation, as shown in Figure 3.2, when $U_0$ increases, the $P_0$ increases as well accordingly. These two parameter have an approximately square relation.

For the $\cos\phi_0 = f(U_0)$ relation, as shown in Figure 3.3, when $U_0$ increases, the $\cos\phi_0 = f(U_0)$ increases as well accordingly. However, $\cos\phi_0 = f(U_0)$ stop increasing when it reaches a certain maximum value, and then starts decreasing. That maximum value is when the highest transformation efficiency can be achieved.
Short circuit characteristics

For the $U_k = f(I_k)$ relation, as shown in Figure 3.4, when $I_k$ increases, the $U_k$ increases as well accordingly, and these two parameters have quite good linear relationship. This is because when it is in short circuit condition, the leakage situation is not saturated, and the short circuit impedance can be regarded as a constant.

For the $P_k = f(I_k)$ relation, as shown in Figure 3.5, when $I_k$ increases, the $P_k$ increases as well accordingly. These two parameter have an approximately exponential relation. This is because the short circuit loss $P_k$ is proportional to the square of $I_k$.

For the $\cos \phi_k = f(I_k)$ relation, as shown in Figure 3.6, the $\cos \phi_k = f(I_k)$ virtually does not change with the change of $I_k$. This is because the short circuit condition make the load of the primary side voltage virtually never changes.

No load excitation parameters

The T equivalent circuit that is obtained based on the analysis of short circuit experiment and no load condition experiment. This is an approximation version of that largely simplified the circuit.

It can be clearly seen that when the secondary circuit is open circuit as that in no load test, all the current flows through that excitation branch in the middle. Also, the values of the $R_l$ and $X_l$ are actually very small compared with that of the excitation parameters. Based on these principles, the related parameters were obtained.

Figure 4.1: Equivalent T circuit
Short circuit excitation parameters

The equivalent circuit of open circuit condition (no load) is presented in Figure 4.2.

![Approximate equivalent circuit]

In the real transformer that is not ideal, $R_{eq}$ and $X_{eq}$ were derived from the calculated excitation parameters which determinate the real loss of the circuit.

When the input voltage is very small thus can be ignored, the current flows through the excitation branch is very small and thus can be ignored as well. An therefore the $R_{eq}$ and $X_{eq}$ can be regarded as without the excitation branch dividing the current.

Based on the obtained excitation parameters, we subsequently obtained the parameters for equivalent circuit:

$$R_{eq} = r_K$$
$$X_{eq} = X_K = 0.825\Omega$$
Section 5

Conclusion

5.1 Achievement

The characteristics of a single-phase transformer in no load condition and short circuit condition respectively were experimentally examined and understood deeply by conducting related calculation and analysis based on their derived values of excitation parameters.

Also, the experimental skills were facilitated in this lab experience as well: the wiring skill and measurement skill were practiced and the experimental results obtained were actually with reasonable accuracy compared with their corresponding theoretical results.

5.2 Limitation

It can be seen that there is a slight error of the experimental results, for example the transformation ratio. Possible causes included both accidental error and systematical error. For the accidental error, one possible cause may be that the experimenters might have not read the experimental results from the measurement apparatus carefully enough so that after several times of calculations and approximations, the obtained experimental values have been quite different from the accurate ones. Also, the apparatus accuracy and working condition may also have influenced the results.

5.3 Suggestion

It is suggested that high-quality apparatus should be applied in the lab. During the lab, there were several broken apparatus at the beginning and this situation made it quite suspectable that whether the other “unbroken” apparatus really had good working condition.

Also, the accuracy of the apparatus is suggested that they should be improved. For example, the wattmeter had only an accuracy of 0.1, which made the reading of the measured values quite unreliable when the changes between two adjacent groups of measurements are quite small.
Appendix A

Pre-lab Question

• (1) What are the features of no load and short circuit tests of a transformer, respectively? To which side should the power supply be connected during each test and why?

  – (a) (Features can be seen in Discussion Part in detail); For the no load test, the power supply is connected to the low-voltage side, and the high-voltage side is open-circuited. This is because
  
  – (b) (Features can be seen in Discussion Part in detail); For the short-circuit test, the terminals of low-voltage side are short-circuited, and the terminals of the high-voltage side are connected to a variable voltage supply. This is because

• (2) How should the instruments be connected to avoid measurement errors during no load and short circuit tests? How should the wattmeter W be connected to a circuit?

  – (a) The ammeter should be placed near to the transformer to avoid getting influenced by the current through voltmeter.
  
  – (b) The voltmeter should be placed near to the transformer to avoid getting influenced by the voltage through ammeter.
  
  – (c) Since the wattmeter is actually composed of an ammeter and a voltmeter, the connection methods should follow theirs respectively: the voltmeter should be connected in parallel with measured segment while the ammeter should be connected in series. Also, two stars marks of the terminals of these two meters should be connected with a wire to ensure that they have the same potential level.