

THE TRANSFORMER

LAB ELEC 7

REFERENCES: PASCO *Transformer Notes*

Physics for Scientists and Engineers, Tipler, 4th Ed., Vol. 2

INTRODUCTION

Nearly all of today's electrical energy is produced as alternating current by electrical generators. The great advantage over direct current is that alternating current can be transformed changing the voltage and current values in relation to each other over a very large range of values. The benefit is that electricity can then be transmitted at very high voltage, V , over long distances at very low current, I , with an amount of electric power, P , delivered according to $P=IV$ and at very low power or energy loss. This is because transmission loss is largely a consequence of electrical heating given by $H=I^2R$ where H is heat produced per time, R electrical resistance. This follows when the transmission line loss is minimized by the transmission line resistance being small and especially that current I is small which is squared in the relationship. As noted, current I by transforming can be made very small and copper, a very good conducting material having very low resistivity and quite plentiful, is the commonly used material for electricity transmission lines. The electrical energy then can be produced at "safe" voltages, transformed to high voltages to the transmission lines, then reduced to "safe" voltages for use in such as factories and homes. Transformers by magnetic induction enable these changes in voltage and current. Our U.S. power is produced and delivered as sinusoidal current at a frequency of 60Hz and commonly delivered at voltages of about: 110V, 220V, and 440V.

This alternating current is quite easily produced by magnetic induction in generator coils, designed to produce a sinusoidal emf. Such a sinusoidal emf input to an inductor, a capacitor, or a resistor is as well sinusoidal, however, generally phase shifts occur between the generated emf and that involving induction and or capacitance. With sinusoidal emfs and currents, their maximum values are easily related. Root-mean-square (rms) values are typically computed which for rms current, $I_{rms} = \sqrt{(I^2)_{av}}$ and for rms emf, $E_{rms} = \sqrt{(E^2)_{av}}$. The average power, P_{av} , dissipated in a resistor having a resistance R is given by $P_{av} = I_{rms}^2 R$ and also by $P_{av} = E_{rms} I_{rms}$. Further for such as a resistive circuit, $I_{rms} = E_{rms}/R$ or $I_{rms} = V_{R,rms}/R$ and $I_{rms} = P_{av}/E_{rms}$, these relationship thus being analogous to corresponding direct current relationships.

Now a commercial transformer is composed typically of two conductive wire coils wound around a common laminated soft iron core. The coil which carries the input current is called the primary and the other coil is the secondary. The primary and secondary coils might be exchanged in the circuit so that the coils exchange the primary/secondary functions. The alternating emf applied to the primary coil induces an

alternating emf in the nearby secondary coil circuit as a result of the mutual induction of the two coils. The iron core guides and concentrates the magnetic effect produced so that the magnetic flux almost completely links the two coils. Even though small, the coils have some resistance so some energy loss occurs due to Joule heating and also small losses resulting from current loops and hysteresis set up in the iron core. Electrical power grid transformers are commonly said to be 90 to 95% efficient. For theoretical considerations we will idealize considering no power loss with power in set equal to power out, that is $P_{pri} = P_{sec}$ or $I_{pri} V_{pri} = I_{sec} V_{sec}$. Accordingly at a certain power level P , increasing V results in I being reduced and vice versa. In consideration of magnetic flux per turn in the primary coil and for negligible flux leakage from the iron core, the magnetic flux per turn is the same for both coils so that $N_{pri}/V_{pri} = N_{sec}/V_{sec}$ where N is the number of turns in a coil. Rewriting $V_{sec} = (N_{sec}/N_{pri}) V_{pri}$ and if N_{sec} is larger than N_{pri} , then V_{sec} is greater than V_{pri} and we have a step-up transformer. Likewise with N_{pri} larger than N_{sec} , then a step-down transformer. If a resistance load is put across secondary coil then there will be a current I_{sec} in the secondary circuit that will be in phase with V_{sec} across the resistance. This Current I_{sec} sets up an additional flux through each turn proportional to $N_{sec} I_{sec}$ which opposes the magnetizing current in the primary. Now the voltage across the primary coil is according to the input emf such as of the generator, so is not affected by the secondary. The total flux in the iron core must be the same as when there is no load across the secondary which means that the primary coil draws an additional current I_{pri} to sustain the original flux. The flux through each turn produced by this I_{pri} is proportional to $N_{pri} I_{pri}$ and I_{pri} is related to I_{sec} by

$$N_{pri} I_{pri} = -N_{sec} I_{sec} \quad \text{Eq. (1).}$$

With these currents 180° out of phase thus producing counteracting fluxes and I_{sec} is in phase with V_{sec} , then I_{pri} is in phase with the applied emf. With the power input $V_{pri,rms} I_{pri,rms}$ and power output $V_{sec,rms} I_{sec,rms}$ and with the magnetizing current not contributing to power input being 90° out of phase with input voltage, then if no losses

$$V_{pri,rms} I_{pri,rms} = V_{sec,rms} I_{sec,rms} \quad \text{Eq. (2).}$$

Generally the additional primary current I_{pri} is much larger than the original magnetizing current drawn from the generator when no load across the secondary. If the magnetizing current can be neglected, Eq. (2) then relates the total power in the primary and secondary transformer circuits.

Practically for our work, it should be noted that electrical meters for measuring alternating currents and voltages generally give root-mean-square (rms) values.

PURPOSE

To observe and study the function of a transformer and relate and compare such as current, voltage and power in the secondary coil with respect to the primary coil.

MATERIALS

transformer
(coils and iron core)
ac power supply or variac
ac ammeter (2)

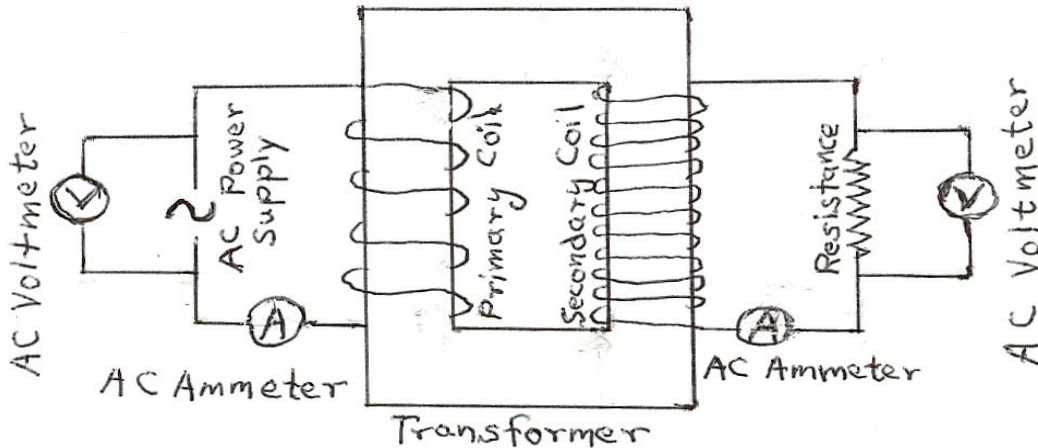
ac voltmeter (2)
decade resistance box
power strip
connecting wires

PRELIMINARY QUESTIONS

1. Why are transformers not used to change the voltage of constant direct currents?
2. Why would a power company transmit electricity at 100s of thousands of volts to a city 300 miles distance?
3. What are the reasons that a commercial transformer core is composed of iron, that it is soft iron, and that it is built up of insulated layers of soft iron plates?
4. Explain the basis of maximum power and average power of sinusoidal alternating current differing from each other.
5. Power company transformers are often designed to provide some cooling; explain.

PROCEDURE

1. Set up the electrical circuit according to the diagram shown. Unless stated otherwise, have the primary coil (with the smaller number of turns) fully inserted into the center of the secondary coil and the solid soft iron core fully inserted as well.
2. You will note that to measure electric current, that is the rate of flow of electricity, the ammeter is placed in series at a position of interest and that for voltage or electrical potential different the voltmeter is placed parallel with the electrical component for which the voltage is of interest. Check that the meter electrical leads are inserted into the desired labeled meter ports and set each meter selection indicator to the proper function whether ac current or ac voltage and on an appropriate range scale for the particular measurement.



3. It is to be noted that these meters, when being used as an ac ammeter or ac voltmeter, indicate measurements in root-mean-square, rms current in amperes and rms voltage in volts (refer to the INTRODUCTION section for reference to rms values).
4. So as not to overload the circuit, to limit heating, and to provide adequate electricity flow for good measurement; we suggest starting with about 1.0 volt input to the primary coil with the decade resistance box, that is, with the resistance across the secondary coil set for 50Ω . Keep this power supply input setting the same throughout the experiment. (the actual primary voltage and current values will change some as the resistance is changed).
5. Guided by the DATA TABLE, proceed to take a set of data for the resistances given, ranging from 50Ω to 1000Ω (or actually to 999Ω , the decade resistance box limitation) by 50Ω increments. Take and record in the DATA TABLE for each resistance, the voltage and current of the transformer primary coil and of the secondary coil.
6. For the last two DATA TABLE entries also with 999Ω resistance, take a data set (still without changing the power input setting) with the primary coil fully inserted into the secondary coil but with the iron core in about one-half the length of the primary coil and then finally a data set with the iron core fully inserted into the primary coil but primary coil along with the iron coil inserted about one-half the length of the secondary coil core.

DATA TABLE

| $R_{pri}=0.2\Omega$ $R_{sec}=76.0\Omega$ | Primary Coil $N_{pri}=235$ turns | | | Secondary Coil $N_{sec}=2920$ turns | | | | | | | |
|---|-------------------------------------|------------------------------------|-------------------------------|--|------------------------------------|-------------------------------|-------------------|---------------------|--------------------------|--------------------------|-------------------|
| Resistance (Ω) R | Voltage (V) rms V_{pi} | Current (A) rms I_{pri} | Power (W) P_{pri} | Voltage (V) rms V_{sec} | Current (A) rms I_{sec} | Power (W) P_{sec} | $I_{sec}R$ (V) | I_{sec}^2R (W) | $P_{pri}-P_{sec}$ (W) | P_{sec}/P_{pri} (%) | V_{sec}/V_{pri} |
| 50 | | | | | | | | | | | |
| 100 | | | | | | | | | | | |
| 150 | | | | | | | | | | | |
| 200 | | | | | | | | | | | |
| 250 | | | | | | | | | | | |
| 300 | | | | | | | | | | | |
| 350 | | | | | | | | | | | |
| 400 | | | | | | | | | | | |
| 450 | | | | | | | | | | | |
| 500 | | | | | | | | | | | |
| 550 | | | | | | | | | | | |
| 600 | | | | | | | | | | | |
| 650 | | | | | | | | | | | |
| 700 | | | | | | | | | | | |
| 750 | | | | | | | | | | | |
| 800 | | | | | | | | | | | |
| 850 | | | | | | | | | | | |
| 900 | | | | | | | | | | | |
| 950 | | | | | | | | | | | |
| 999 | | | | | | | | | | | |
| ½ core 999 | | | | | | | | | | | |
| ½ coil 999 | | | | | | | | | | | |

ANALYSIS

1. Proceed with data treatment/analysis much of which is outlined according to the headings of the DATA TABLE.
2. Compute the power in the primary coil, $P_{\text{pri}} = I_{\text{pri}} V_{\text{pri}}$ and record the values in the DATA TABLE. Compute the power in the secondary coil, $P_{\text{sec}} = I_{\text{sec}} V_{\text{sec}}$ and record the values in the DATA TABLE. Compute the power expended in the resistors as a result of resistive heating given by $I_{\text{sec}}^2 R$ and record the values in the DATA TABLE. Compare and discuss this power loss in the various resistors with the corresponding power in the secondary coil $P_{\text{sec}} = I_{\text{sec}} V_{\text{sec}}$.
3. Compute and record in the DATA TABLE, the percent ratios of the secondary coil power to the primary coil power, $P_{\text{sec}}/P_{\text{pri}}$ (%). Also compute and record the actual power losses from primary coil to secondary coil, $P_{\text{pri}} - P_{\text{sec}}$. Comment on these power losses differences. Discuss to what these power losses might be attributed and the 90 to 95% efficiencies of power company transformers. In these comparisons note any trends in relation to the range in resistance value that is in series with the secondary coil.
4. Compute the voltage drop across the resistors as the product of the secondary current and the resistance, $I_{\text{sec}} \bullet R$ and record the values in the DATA TABLE. Compare and comment on these values in relation to the directly obtained ac voltmeter readings for the various resistances.
5. Compute and record in the DATA TABLE the ratios of the secondary coil voltage to the primary coil voltage. How is such phenomena as these values indicate possible? Explain from a physical perspective that the values obtained make sense.
6. It would be well to plot a graph of the secondary voltage vs. the secondary current. Approximately, what kind of function is implied? Comment on significance of the vertical or secondary voltage intercept. Explain that the secondary current decreases with increasing secondary voltage and the fact that the secondary voltage does increase with increasing resistance R . What significance does the input power have on this plot behavior?
7. Of interest is a graph of secondary power, P_{sec} vs. resistance, R . Does your P_{sec} maximize at about 200Ω for R as we noted with data taken from primary coil voltage inputs of 2.0V, 1.5V, 1.0V or 0.5 volts. Explain/justify that with increasing R the secondary circuit power first increases then decreases (a hint might be $I_{\text{sec}}^2 R$ being involved).
8. Discuss and explain the results of the last two DATA TABLE entries – with iron core partly inserted and with primary coil partly inserted.