CHAPTER 5

TRANSFORMERS

LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. State the meaning of "transformer action."

2. State the physical characteristics of a transformer, including the basic parts, common core materials, and main core types.

3. State the names given to the source and load windings of a transformer.

4. State the difference in construction between a high- and a low-voltage transformer.

5. Identify transformer symbols as to the type of transformer each symbol represents and the method used to denote transformer phasing.

6. State the meaning of a "no-load condition" and "exciting current" relative to a transformer.

7. State what causes voltage to be developed across the secondary of a transformer and the effect of cemf in a transformer.

8. State the meaning of leakage flux and its effect on the coefficient of coupling.

9. Identify a transformer as step-up or step-down and state the current ratio of a transformer when given the turns ratio.

10. Solve for primary voltage, secondary voltage, primary current and number of turns in the secondary given various transformer values.

11. State the mathematical relationship between the power in the primary and the power in the secondary of a transformer and compute efficiency of a transformer.

12. State the three power losses in a transformer.

13. State the reason a transformer should not be operated at a lower frequency than that specified for the transformer.

14. List five different types of transformers according to their applications.

15. State the standard color coding for a power transformer.

16. State the general safety precautions you should observe when working with transformers and other electrical components.

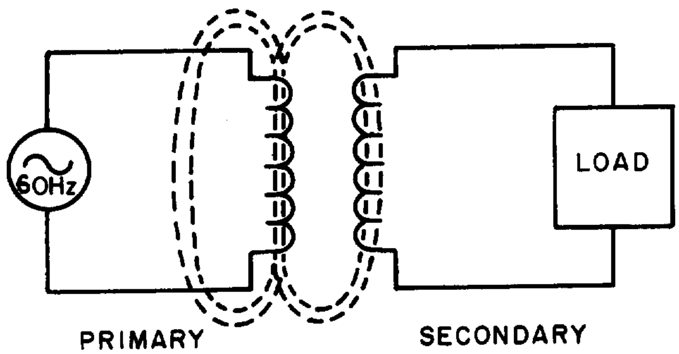

Figure 5-1.—Basic transformer action.

Q2. What are, the three basic parts of a transformer?

THE COMPONENTS OF A TRANSFORMER

Two coils of wire (called windings) are wound on some type of core material. In some cases the coils of wire are wound on a cylindrical or rectangular cardboard form. In effect, the core material is air and the transformer is called an AIR-CORE TRANSFORMER. Transformers used at low frequencies, such as 60 hertz and 400 hertz, require a core of low-reluctance magnetic material, usually iron. This type of transformer is called an IRON-CORE TRANSFORMER. Most power transformers are of the iron-core type. The principle parts of a transformer and their functions are:

- The CORE, which provides a path for the magnetic lines of flux.
- The PRIMARY WINDING, which receives energy from the ac source.
- The SECONDARY WINDING, which receives energy from the primary winding and delivers it to the load.
- The ENCLOSURE, which protects the above components from dirt, moisture, and mechanical damage.

CORE CHARACTERISTICS

The composition of a transformer core depends on such factors as voltage, current, and frequency. Size limitations and construction costs are also factors to be considered. Commonly used core materials are air, soft iron, and steel. Each of these materials is suitable for particular applications and unsuitable for others. Generally, air-core transformers are used when the voltage source has a high frequency (above 20 kHz). Iron-core transformers are usually used when the source frequency is low (below 20 kHz). A soft-iron-core transformer is very useful where the transformer must be physically small, yet efficient. The iron-core transformer provides better power transfer than does the air-core transformer. A transformer whose core is constructed of laminated sheets of steel dissipates heat readily; thus it provides for the efficient transfer of power. The majority of transformers you will encounter in Navy equipment contain laminated-steel cores. These steel laminations (see figure 5-2) are insulated with a nonconducting material, such as varnish, and then formed into a core. It takes about 50 such laminations to make a core an inch thick. The purpose of the laminations is to reduce certain losses which will be discussed later in this chapter. An important point to secondary, the effect can be duplicated by assuming an inductor to be connected in series with the primary. This series LEAKAGE INDUCTANCE is assumed to drop part of the applied voltage, leaving less voltage across the primary.

Q14. What is "leakage flux?"

Q15. What effect does flux leakage in a transformer have on the coefficient of coupling (K) in the transformer?

TURNS AND VOLTAGE RATIOS

The total voltage induced into the secondary winding of a transformer is determined mainly by the RATIO of the number of turns in the primary to the number of turns in the secondary, and by the amount of voltage applied to the primary. Refer to figure 5-10. Part (A) of the figure shows a transformer whose primary consists of ten turns of wire and whose secondary consists of a single turn of wire. You know that as lines of flux generated by the primary expand and collapse, they cut BOTH the ten turns of the primary and the single turn of the secondary. Since the length of the wire in the secondary is approximately the same as the length of the wire in each turn in the primary, EMF INDUCED INTO THE SECONDARY WILL BE THE SAME AS THE EMF INDUCED INTO EACH TURN IN THE PRIMARY. This means that if the voltage applied to the primary winding is 10 volts, the counter emf in the primary is almost 10 volts. Thus, each turn in the primary will have an induced counter emf of approximately one-tenth of the total applied voltage, or one volt. Since the same flux lines cut the turns in both the secondary and the primary, each turn will have an emf of one volt induced into it. The transformer in part (A) of figure 5-10 has only one turn in the secondary; thus, the emf across the secondary is one volt.

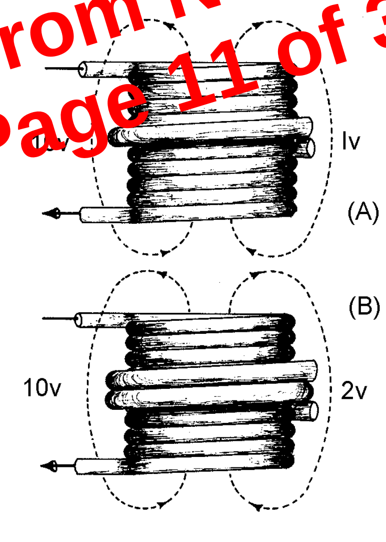

Figure 5-10.—Transformer turns and voltage ratios.

The transformer represented in part (B) of figure 5-10 has a ten-turn primary and a two-turn secondary. Since the flux induces one volt per turn, the total voltage across the secondary is two volts. Notice that the volts per turn are the same for both primary and secondary windings. Since the counter emf in the primary is equal (or almost) to the applied voltage, a proportion may be set up to express the value of the voltage induced in terms of the voltage applied to the primary and the number of turns in each winding. This proportion also shows the relationship between the number of turns in each winding and the voltage across each winding. This proportion is expressed by the equation:

Given:

$$N_P = 400 \text{ turns}$$
$$E_P = 5 \text{ volts}$$
$$E_S = 1 \text{ volt}$$
$$N_S = ? \text{ turns}$$

Solution: $$E_P N_S = E_S N_P$$

Transposing for N_S:

$$N_S = \frac{E_S N_P}{E_P}$$

Substitution: $$N_S = \frac{1 \text{ volt} \times 400 \text{ turns}}{5 \text{ volts}}$$

$$N_S = 80 \text{ turns}$$

Note: The ratio of the voltage (5:1) is equal to the turns ratio (400:80). Sometimes, instead of specific values, you are given a turns or voltage ratio. In this case, you may assume any value for one of the voltages (or turns) and compute the other value from the ratio. For example, if a turn ratio is given as 6:1, you can assume a number of turns for the primary and compute the secondary number of turns (60:10, 36:6, 30:5, etc.).

The transformer in each of the above problems has fewer turns in the secondary than in the primary. As a result, there is less voltage across the secondary than across the primary. A transformer in which the voltage across the secondary is less than the voltage across the primary is called a STEP-DOWN transformer. The ratio of a four-to-one step-down transformer is written as 4:1. A transformer that has fewer turns in the primary than in the secondary will produce a greater voltage across the secondary than the voltage applied to the primary. A transformer in which the voltage across the secondary is greater than the voltage applied to the primary is called a STEP-UP transformer. The ratio of a one-to-four step-up transformer should be written as 1:4. Notice in the two ratios that the value of the primary winding is always stated first.

Q16. Does 1:5 indicate a step-up or step-down transformer?

Q17. A transformer has 500 turns on the primary and 1500 turns on the secondary. If 45 volts are applied to the primary, what is the voltage developed across the secondary? (Assume no losses)

Q18. A transformer has a turns ratio of 7:1. If 5 volts is developed across the secondary, what is the voltage applied to the primary? (Note: E_S is given, what is E_P ?)

Q19. A transformer has 60 volts applied to its primary and 420 volts appearing across its secondary. If there are 800 turns on the primary, what is the number of turns in the secondary?

EFFECT OF A LOAD

When a load device is connected across the secondary winding of a transformer, current flows through the secondary and the load. The magnetic field produced by the current in the secondary interacts with the magnetic field produced by the current in the primary. This interaction results from the mutual inductance between the primary and secondary windings.

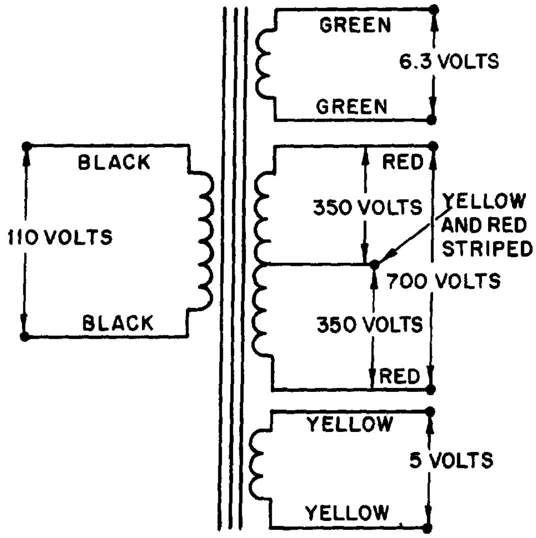

Figure 5-12.—Schematic diagram of a typical power transformer.

There are many types of power transformers. They range in size from the huge transformers weighing several tons-used in power substations of commercial power companies-to very small ones weighing as little as a few ounces-used in electronic equipment.

AUTOTRANSFORMERS

It is not necessary in a transformer for the primary and secondary to be separate and distinct windings. Figure 5-13 is a schematic diagram of what is known as an AUTOTRANSFORMER. Note that a single coil of wire is "tapped" to produce what is electrically a primary and secondary winding. The voltage across the secondary winding has the same relationship to the voltage across the primary that it would have if they were two distinct windings. The movable tap in the secondary is used to select a value of output voltage, either higher or lower than E_P, within the range of the transformer. That is, when the tap is at point A, E_S is less than E_P; when the tap is at point B, E_S is greater than E_P.

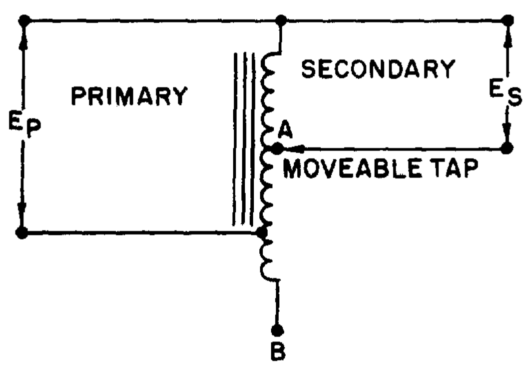

Figure 5-13.—Schematic diagram of an autotransformer.