TECH TIP # 38

HEATING, AIRCONDITIONING & REFRIGERATION DISTRIBUTORS INTERNATIONAL

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More on Impedance (Z)

Assignment 4 in your text material referred to impedance (Z) as the combined effect of resistance, induction and capacitance in an AC circuit (page 30). This Tech Tip will provide you with additional information on this important characteristic of AC circuits.

Inductance is the property of an electric circuit that opposes any change in the current through the circuit. Even a perfectly straight conductor (wire) has some inductance, but significant inductance is added to an AC circuit by coils --- such as is found in motors, control valves, transformers, etc. Inductance is measured in units called “henrys.” The symbol for henrys is (L).

Some of the factors affecting the magnitude of the inductance in henrys are: the number of turns of wire in the coil, the cross sectional area and the kind of magnetic core material placed inside the coil; and the length of the coil.

Frequently, the inductance of a coil is stamped in millihenrys (one thousandths) on the face of the coil, since the henry is somewhat large for many practical circuits in HVACR work.

The opposition offered current flow by coils --- like resistance --- is given in units of ohms and is referred to as inductive reactance (X_L).

Inductive reactance (X_L) is equal to 6.28 times the henrys (L) of the inductance times the AC frequency (F) in hertz. That is:

$$X_L = 6.28 \text{ x } L \text{ x } F$$

Since in the U.S. most AC circuits are 60 cycles per second, the above formula reduces to:

$$X_L \text{ (ohms)} = 376.8 \text{ x } L \text{ (henrys)}$$

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Now the opposition to current flow in an AC circuit with pure resistance and inductive reactance is called impedance (Z) ---from the word “impede” meaning to interfere or slow the progress --- and is determined as follows:

$$Z = \sqrt{R^2 + X_L^2}$$

…where R is, of course, the pure resistance. Thus, Z equals the square root of the sum of the squares of each opposition to flow.

There is yet another factor to the total opposition to flow in an AC circuit --- capacitance.

Capacitance is the property of an AC electric circuit that resists or opposes any change of voltage in the circuit. Capacitance is added to an AC circuit by the addition of a device called a capacitor. Capacitance is measured in units called the “farad.” The farad is a large number so in heating and air conditioning work, you often see capacitors rated in microfarads (one millionth of a farad) or even micromicrofarads.

The opposition to current flow in a capacitive circuit is called capacitive reactance (X_C) and is determined by the following relationship.

$$X_C \text{ (ohms)} = 1/6.28 \text{ x F x C}$$

… where F is the AC frequency (60 in the U.S.) and C is the capacitance in farads.

Now the opposition to current flow in an AC circuit with just pure resistance and capacitive reactance is as follows:

$$Z = \sqrt{R^2 + X_C^2}$$

which is similar to the formula for impedance in an inductive circuit.

If there is both inductive and capacitive reactance in an AC circuit, one characteristic will cause the current to lag the voltage and the other to lead the voltage. So, the net reactance is the difference between the inductive reactance and the capacitive reactance. This is determined by subtracting whichever of the two (X_L or X_C is smaller from the larger. If X_L or the inductive reactance is larger, then the current will lag the voltage. If X_C or the capacitive reactance is larger, then the current will lead the voltage.

Thus, total impedance (Z) is: $Z = \sqrt{R^2 + (X_L - X_C)^2}$ if X_L is larger than X_C

and $Z = \sqrt{R^2 + (X_C - X_L)^2}$ if X_C is larger than X_L.

If X_L and X_C are equal in value, their effect on the circuit cancels and the circuit is said to be in resonance.

For example, let's assume a 120 volt AC circuit has a resistive load (R) of 8 ohms, an inductive reactance (X_L) of 10 ohms and a capacitive reactance (X_C) of 4 ohms. What is the total impedance (Z) of the circuit and the current flow?

$$Z = \sqrt{8^2 + (10 - 4)^2}$$

$$Z = 10 \text{ ohms}$$

From Ohm's Law for AC circuits (E = I x Z), we find that I = 120/10 or 12 amps; and since X_L is larger than X_C, the current lags the voltage.