ISTANBUL COMMERCE UNIVERSITY

Electrical-Electronics Engineering
EEE202 Electro-technic Laboratory

Theory

Part 5

Contents

COILS

13.1 INTRODUCTION

Coils are the elements which resist AC and DC current in different ways. They are usually used in AC circuits in order to manage AC and differ AC from DC. Also, when electric current passes through coils, they form magnetic field. Because of this, they are widely used in electrical machines (**motors, transformers, etc.**). Coils are also widely used in electrical devices based on electromagnets like relays, bells, contactors and cranes, etc.

When DC current passes through coils, coil highly resist to the current only at the very beginning. After that current reaches its normal value and there will be no change on the current during the operation time. The only resistance is wire’s resistance.

When AC current passes through the same coil, it inducts negative electromotive force (**EMF**) on the coil during the operation time. Figure 12.1 shows the negative EMF from the beginning of alternans to the point where it reaches its maximum.

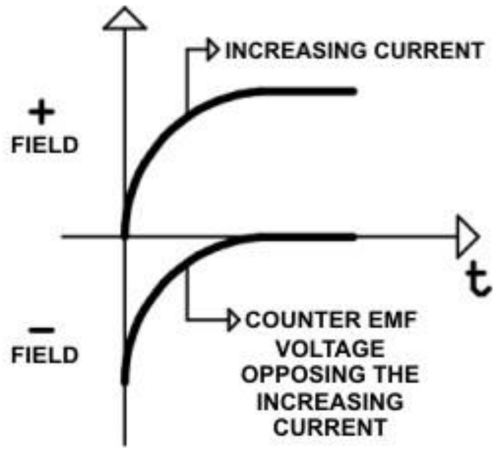

Figure 12.1

Negative EMF resist AC current. Because of this, coils’ resistance is greater while working in AC than working in DC.

After the maximum point of alternans (while coil current decreases to zero), the negative EMF in the coil tries to maintain the current.

Figure 12.2 shows the effect of negative EMF.

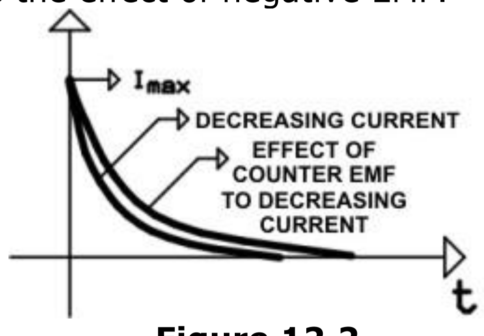

Figure 12.2

It is clear that, coils are elements which can store electric energy in electromagnetic field.

The ability of coil to store electric energy and to resist the current is related with its coil value. Coils are shown with letter '**L**' and their unit is '**Henry**'. Henry is shortly shown with letter '**H**'.

"Henry is the coil value when one volt voltage is inducted in a coil in a change of one ampere of current in one second."

Coil values are also called as **"inductance".** The inductance is large in high frequency circuits.

Because of this the lower multipliers are mostly used in electronics. In figure 12.3, the lower multipliers and their mathematical conversion can bee seen.

UPPER MULTIPLES	LACKING	
MAIN UNIT	(L) HENRY	
LOWER MULTIPLES	(m H) MILI HENRY	1 000mH = 1H
	(μ H) MICRO HENRY	1 000μH = 1mH

Figure 12.3

Generally, coils with high inductance are used in electrics and coils with low inductance are used in electronics. In lower frequencies (up to 20 KHz) and in DC, the inductances of coils are larger. Higher inductance coils have larger turns and their kernel have larger conductivity. Kernels increase coils inductance directly proportional with their conductivities. There exist carcass and air between coil and its kernel. Conductivity in this subject is ratio of magnitude of the force vector between poles of a magnet when there is that material and air. It is also called as permeability. It is shown with the letter "**μ**" (**mü**). "**μ**" (**mü**) is generally small. Metals have low resistivity.

Materials with high permeability are done by experiments.

For example; Ferro- ferrite (**Fe_3 0_4**), cupper-Ferro- ferrite (**Cu $Fe_2 0_4$**), lead-Ferro-Ferrite (**Pb $Fe_2 0_4$**) and iron combinations have resistivities nearly 10^8R and magnetic permeabilities are between100-200. These cores are called "**ferrous**" cores. Ferrite is a nonmetal with high conductivity. Ferrite cores have conductivities between 10 and 200.

The cores in coils must have low eddy current loss. For example, if iron is used as a core in a coil, eddy current occur in iron and this causes eddy current loss. Eddy current loss heats the core and this causes loss of electric energy. Eddy current losses can be reduced by using a combination of silisium and iron. The conductivity of core can be made zero by using insulators like dope and this reduces the eddy current loss. In lower frequency circuits, this structure is used and mechanical robustness and lower costs are achieved in ac machines (**motors, transformers etc.**)

In high frequency circuits (**larger than 20 KHz**), silisium iron combination is not used since they have higher loss, ferrite core coils are used instead.

In too high frequency or a certain frequency band circuits, adjustable core coils are used. In these kinds of coils, core is moved in coil and inductance is adjusted. In lower inductance coils, cores which have lower conductance than air are used. Brass is an example of this kind of material. It reduces the coil inductance.

Coils with different cores have different symbols. These symbols are shown in figure 12.4.

Figure 12.4

Coils with higher inductance can be achieved by using a structure that will capture magnetic forces inside and outside the coil.

Figure 12.5 shows two different coil structures.

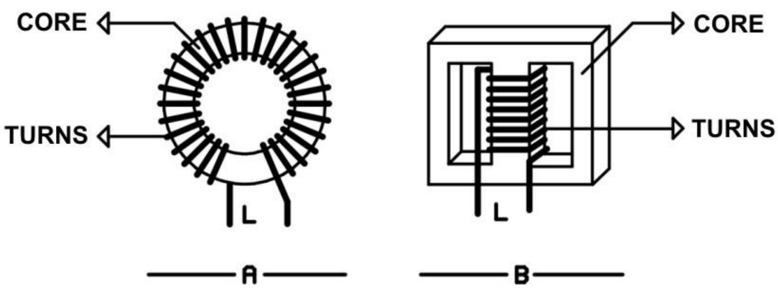

Figure 12.5

The coil in figure 12.5A is called as "**trio coil**" trio coils are used in SMPS (**S**witch **M**ode **P**ower **S**upply) circuits. The coil in figure 12.5A is called as "**transformer type**" coil. These coils are used in transformer and filter circuits.

13.2 MEASURMENT AND INDICATION OF COIL VALUES

Coil values are indicated in two different methods. Both methods use the unit micro Henry (**μH**). In first method, numbers formed by three digits are used. The first and the second digits form the number, the third digit is the multiplier. For example, if the number 124 is in a coil. The inductance of this coil is:

L=120000μH**=**120mH.

The second method is same as the four band resistance color code. For example the colors in a coil are yellow, violet, red and gold then this coil has an inductance of:

L=4700μH the tolerance is %5.

Some coils have high inductances like 100H. This inductance are shown directly writing the value and unit.

The inductance is measured by inductance meter. Inductance meters give a 1 KHz small current to the coil and measure the inductance with the help of this current. Coil inductances must be measured off the circuit. The ohmic resistance of the coil is measured by ohmmeter.

Besides their inductances, the current and the frequency is also important for coils. In electric circuits, usually current is high and frequency is low. The wire of the coil must be thick enough for the high current. In electronic circuits, usually current is low and frequency is high. In these circuits, cores must be chosen convenient for the frequency.

13.3 COIL CONNECTIONS

Coils are sometimes used in serially or parallel connected in electric and electronic circuits. Since coils inductances are AC current resistances, they are mathematically calculated like resistances.

1. Serial connection: By serial connection, the inductance values are increased. Figure 12.6 shows the serial connection of three coils.

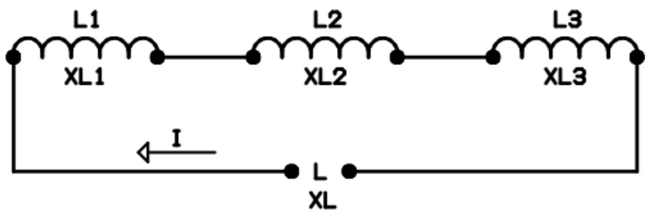

Figure 12.6

In serial connection, total inductance is the sum of all coil inductances.

L=L1+L2+L3

In serial connection total inductive reactance is the sum of all inductive reactance.

XL=XL1+XL2+XL3

Circuit current is found by Ohm’s law.

$$I = \frac{E}{XL}$$

In serially connected coil circuit, the maximum circuit current is the current passing through the coil with minimum current.

Circuit voltage is divided directly proportional to the inductive reactance of the coils.

E1=I.XL1, **E2=**I.XL2, **E3=**I.XL3
E=E1+E2+E3

Example: Two coils one with inductance of 2H and max current of 2A and the other with inductance 3H and current 0,5A are serially connected to a AC voltage source with 220V and 50Hz.

A-Find the total inductance?
B-Find the total inductive reactance?
C-Find the circuit current?
D-Find the coil voltages?
E-Find the maximum current passing through the circuit?

Solution:

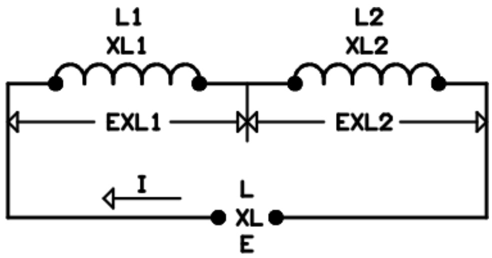

Figure 12.7

A)
L=L1+L2
L=2+3
L=5 H

B)
XL1=2πfL1
XL1=6,28.50.2
XL1=628R

XL2=2πfL2
XL2=6,28.50.3
XL2=942R

XL=XL1+XL2
XL=628+942
XL=1570R

C)

$$I = \frac{E}{XL} = \frac{220}{1570} = 0{,}14A$$

D)
EL1=I.XL1
EL1=0,14.628
EL1=87,9V

EL2=I.XL2
EL2=0,14.942
EL2=131,9V

E=EL1+EL2
E=87,9+131,9
E=219,82

Circuit voltage is 220V. Mathematical difference is because of calculation error.

E) Since the maximum current is equal to the current of the coil with the minimum current;
I=0,5A'dir.

2. Paralel connection: Parallel connection is used in order to increase the current capacity of the circuit. Figure 12.8 shows the parallel connection of three coils.

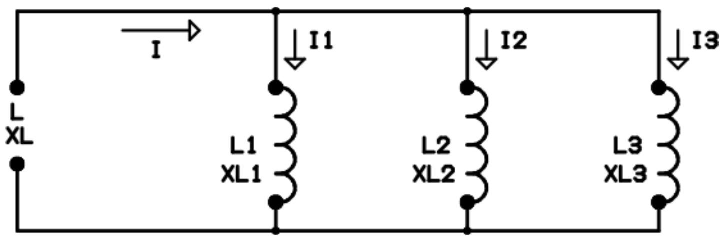

Figure 12.8

In parallel connection, total inductance is found by the equation below. Total inductance is smaller than the inductance of the coil with the smallest inductance.

$$\frac{1}{L}=\frac{1}{L1}+\frac{1}{L2}+\frac{1}{L3}$$

In parallel connected circuits, total inductance is found by the equation below.

$$\frac{1}{XL}=\frac{1}{XL1}+\frac{1}{XL2}+\frac{1}{XL3}$$

Circuit current is calculated by Ohm's law.

$$I = \frac{E}{XL}$$

The current of the each coil is calculated by;

$$I1 = \frac{E}{XL1} \quad , \quad I2 = \frac{E}{XL2} \quad , \quad I3 = \frac{E}{XL3}\text{'}t\ddot{u}r.$$

The circuit current is the sum of all currents.
I=I1+I2+I3

Example: Two coils one with inductance of 3H and max current of 2A and the other with inductance 6H and current 5A are parallel connected to an AC voltage source with 220V and 50Hz.

A- Find the total inductance?
B- Find the total inductive reactance?
C- Find the circuit current?
D- Find the coil currents?
E- Find the maximum current passing through the circuit?

Solution:

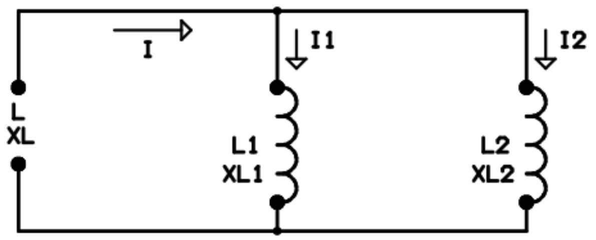

Figure 12.9

A)

$$\frac{1}{L} = \frac{1}{L1} + \frac{1}{L2}$$

$$\frac{1}{L} = \frac{1}{3} + \frac{1}{6}$$

$$\frac{1}{L} = \frac{3}{6}$$

$$L = \frac{6}{3}$$

L=2 H

B)

XL1=2πfL
XL1=6,28.50.3
XL1=942R

XL2=2πfL
XL2=6,28.50.6
XL2=1884

$$\frac{1}{XL}=\frac{1}{XL1}+\frac{1}{XL2}$$

$$\frac{1}{XL}=\frac{1}{942}+\frac{1}{1884}$$

$$\frac{1}{XL}=\frac{3}{1884}$$

$$XL=\frac{1884}{3}$$

XL=628R

C)

$$I=\frac{E}{XL}=\frac{220}{628}=0,35A$$

D)

$$I1=\frac{E}{XL1}=\frac{220}{942}=0,23A$$

$$I2=\frac{E}{XL2}=\frac{220}{1884}=0,12A$$

The validation of equations is;

I=I1+I2
0,35=0,23+0,12
0,35=0,35

E)

I=2+5=7A

EXAMINATION OF COILS IN ALTERNATING CURRENT

14.1 INTRODUCTION

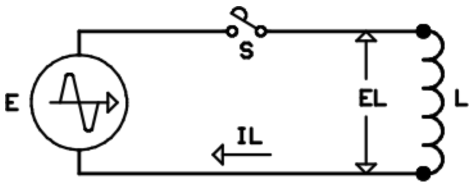

Figure 13.1

In figure 13.1 when the S switch is closed, voltage is applied to the coil. Coil inductance gradually increases and reaches to its normal value. If we examine the vector diagram of this kind circuit we notice that current lags the voltage 90^0 .

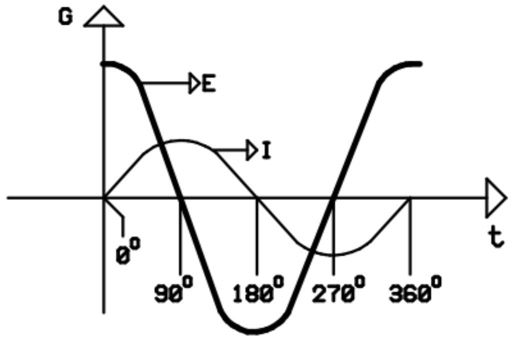

Figure 13.2

0^0 is the time when the switch is closed. At this moment voltage is maximum level and current is zero.

Between 0^0-90^0 while instantaneous voltage decreases, instantaneous current increases in positive direction. At90^0 voltage is zero and current is maximum.

Between 90^0-180^0 while instantaneous voltage increases in negative direction, instantaneous current decreases to zero. At180^0 voltage is maximum level at negative and current is zero.

Between 180^0-270^0 while instantaneous voltage increases to zero, instantaneous current increases to maximum value in negative direction. At 270^0 voltage is zero and current is maximum in negative direction.

Between 270^0-360^0 while instantaneous voltage increases in positive direction, instantaneous current decreases to zero.

Figure 13.3 shows the phase diagram of this kind circuit.

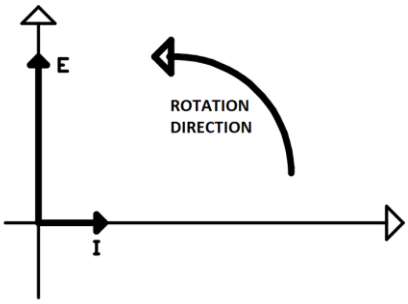

Figure 13.3

If voltage leads current, the circuit is called as "**inductive circuit**" .The examples are electric motors, transformer and electromagnets.

For an AC circuit includes only a coil voltage leads current 90^0 or **π/2** radians. In these circuits, the instantaneous voltage and current equations are given below. If the current is reference;

$$i = Imax.Sinwt$$
$$e = Emax.Sin(wt + \pi / 2)$$

If the voltage is reference;

$$e = E\,max.Sinwt$$
$$i = Imax.Sin(wt - \pi / 2)$$.

In the previous discussion, the ohmic resistance of the coil is ignored but this is not the case. The ohmic resistance of the coils are called as internal resistance. Internal resistance is modeled as a serially connected resistance. Internal resistance decreases the coil current. This loss is called as copper loss. Besides the cupper loss there exist eddy current loss, dielectric loss and hysterisis loss. These are modeled as a parallel connected resistance.

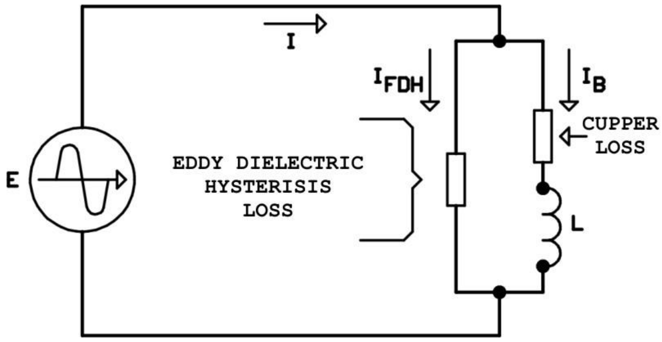

Figure 13.4

Figure 13.4 shows the losses in a coil. Eddy, dielectric and hysterisis losses cause some current loss in the circuit. The current loss is generally small. Cupper loss decreases the current passing through coil. Cupper loss is big enough and it cannot be ignored. If we examine the circuit in the view of the source, eddy, dielectric and hysterisis losses increases the current and cupper loss decreases the current. Cupper loss is the most significant loss. Because of this, the measured current is smaller than the calculated current.

14.2 INDUCTIVE REACTANCE

The resistance of an AC circuit is called as impedance. If this is composed of only ohmic resistances the impedance of the circuit is equal to the DC resistance. If a coil is connected to an AC source there is another resistance, the negative EMF, other than the ohmic resistance. The resistance of the coil in AC is called as "**inductive reactance**" . The unit of inductive reactance is also ohm. Inductive reactance is directly proportional with the coil inductance and the frequency of the circuit. The equation of inductive reactance is:

XL=2пfL'dir.

In this equation;
XL= inductive reactance (**Ohm**)
F = frequency (**Hertz**)
L = coil inductance (**Henri**)
2п = constant (**6,28**).

Example: A coil with 1500mH inductance is connected to an AC source with 220V 50Hz. Find inductive reactance and circuit current?

Solution:

XL=2пfL
XL=6,28.50.1,5=471R.

$$I = \frac{E}{XL} = \frac{220}{471} = 0{,}46A$$

Coil impedance is the vector sum of inductive reactance and ohmic resistance of the coil. In AC circuits, ohmic resistance and inductive reactance are shown as serially connected. In low frequency circuits ohmic resistance cannot be ignored.

14.3 QUALITY FACTOR

The ohmic resistances of the coils decrease the efficiency especially in low frequency AC circuits. The quality factor is a degree of efficiency in coils. It is shown with the letter "**Q**". Its equation is:

$$Q = \frac{XL}{R}$$

In this equation;
Q = Quality factor
XL= inductive reactance (**Ohm**)
R = ohmic resistance (**Ohm**).

The ohmic resistance of a coil is a DC resistance. It is fixed for a coil. Inductive reactance increases with the increasing frequency. If the quality factor is high, the inductance value is higher than ohmic resistance. Quality factor is directly proportional with the frequency.

Example: Find the coil's quality factor with 100R Ohmic resistance and 2H inductance in a 500 Hz frequency circuit?
Solution:

XL=2пfL
XL=2.3,14.500.2
XL=6280R

$$Q = \frac{XL}{R}$$

$$Q = \frac{6280}{100} = 62{,}8'dir.$$

In high frequency circuits, the inductance of the coils are usually small. Because of this they have less turns. The ohmic resistance is ignored in this kind of coils. In AC circuits if the ohmic resistance is ignored, the Ohm's law is applied using inductive reactance instead of resistances.

$$I = \frac{E}{XL} \quad , \quad E = I.XL \quad , \quad XL = \frac{E}{I}$$

14.4 POWER IN AC CIRCUITS WITH COILS

For a coil circuit current lags the voltage 90^0. Then the power factor (**Cos Φ**) is zero since the cosine of 90^0 is zero. Then the active power of the circuit is zero.
P=E.I.Cos Φ
Φ=90^0
Cos90^0=0
P=0

The current meters measure the real power. Theoretically, loads consist of only coils consume no power. It is bad for electric suppliers. Because of this power factor is made "1" by using additional components. The power of these kind circuits is calculated as reactive power (**Q**).

Q=E.I.Sin Φ
Φ=90^0
Sin90^0=1
Q=E.I VAr.

Figure 13.5 shows the vector diagram of a circuit consist of only coils.

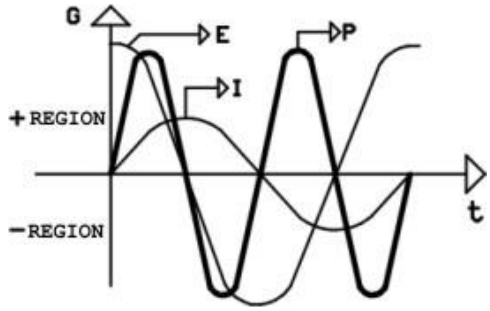

Figure 13.5

Coils can store the electric energy. Let's try to explain the current direction in the power curve. When both current and voltage is in either positive or negative region i.e. they have the same signs, electric energy is stored in the magnetic field of the coil. When voltage and current have different signs, the stored energy is given to the AC source.

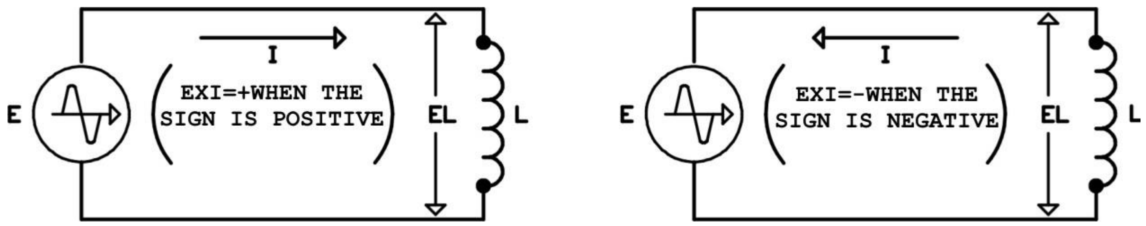

Figure 13.6

Figure 13.6 shows the direction of current in AC circuits. If the alternans of the power curve is positive, this instantaneous power is positive. If the alternans of the power curve is negative, this instantaneous power is negative. In an AC circuit if the area under the curve is zero, the total power is zero.

Coils have an internal resistance. Because of this they also consume real power. If there is a coil in an AC circuit, coils' internal resistance resist as if it is a real resistance. This makes the circuit consist of a coil and a resistance not only an ideal coil and the phase difference between voltage and current is lower than 90^0.

In the experiment about coils in AC circuits, the internal resistance of the coil is ignored.