SIXTH WEEK

MAGNETS - MAGNETISM - MAGNETIC CIRCUITS. G.B.Todd,RM1c

QUESTION #1. What is a magnet? What is meant by poles of a magnet? How are the strength of poles represented?

ANSWER #1. A body which will attract iron or steel is called a magnet. A handful of iron filings, when placed on a sheet of paper or glass above a bar magnet, will arrange themselves in lines, passing around the magnet from one end to another. The lines will come out of one end of the magnet and enter the other end.

Those regions where the attraction for iron or steel is the greatest, are called the poles of a magnet. The region where the lines come out is called the North pole and the region where they enter is called the south pole of a bar magnet. These poles are not points but entire regions. No matter where the lines come out of a magnet, that part is a North pole and likewise, wherever they enter is a South Pole. The

Strength of these poles is represented by magnetic lines of force. They always leave the magnet at the North pole and enter it again at the South pole.

QUESTION #2. What is meant by magnetic lines of force? A magnetic field?

ANSWER #2. The term "magnetic lines of force" is used to represent the direction and amount of force in a space. A magnetic line of force forms a complete circuit, leaving the North pole traversing the air around the magnet, entering the magnet again at the South pole and flowing within the magnet from the South pole back to the North pole.

A space in which there are magnetic lines of force is called a magnetic field. The magnetic field of a magnet has the nature of a whirl, and is the flux or current of magnetism flowing around its circuit. It must be thoroughly understood that the flux flows in a complete magnetic circuit. The lines do not start at the North pole and end at the South pole. They continue through the magnet from the South pole to the North pole thus forming a complete circuit.

QUESTION #3. What type magnet produces no magnetic field? What are the uses of this magnet? What is meant by a broken-ring or horseshoe magnet? What are its uses? Why?

ANSWER #3. A ring magnet produces no external field. The lines of force all lie within the material, so that such a magnet has no poles. This type of magnet is used in transformers and types of meters where no external field is desired.

A broken-ring or horseshoe magnet is a ring magnet which has been broken so that two poles are produced, having a very strong external field, small in area. This type of magnet is used to form the magnetic circuit of motors and generators. It is used because motors and generators require a very intense field in a limited air space so that a maximum number of lines will be cut.

QUESTION #4. Define reluctance.

ANSWER #4. The resistance which a substance offers to the magnetic flux is called the reluctance. Just as the resistance which a substance offers to an electrical current is called the resistance. Copper and aluminum is used in an electrical circuit because the resistance they offer to a flow of electrical current is low. Similarly, iron and steel are used in a magnetic circuit because they have a very low reluctance. In some cases the magnetic flux is made to flow thru air. An electrical current is never made to flow thru air because the resistance is very high. But the reluctance of air is low in comparison. Were the reluctance of air as much greater than the reluctanc of iron than the resistance of air is greater than the resistance it would be impossible to make a powerful electromagnet such as is required in a generator or a motor. Because the reluctance of iron and steel are less than air, the lines of force traveling from the North Pole of a magnet, through the surrounding air space to the South Pole, would be deflected by a piece of iron or steel near the path. A greater number of lines would be set up in the iron entering at one end and leaving at the other, thus making the piece of iron or steel, temporarily, a magnet. The region where the lines left the piece of iron would be the North Pole. The lines would go from there back to the South Pole of the magnet. Therefore we have two magnets with unlike poles adjacent and, since the lines of force have a contracting nature, like a rubber band, the unlike poles would attract each other. This explains the attraction of a piece of iron or steel to a permanent magnet. From this it is plain to see that, if it were desired to have a certain air space free from magnetic lines, it is only necessary to place a shield of soft iron in the field. As the reluctance of iron is lower than that of air, most of the lines would travel through the iron, and the air would be practically free. In this case the space is not insulated from the magnetic flux, but the flux is shunted around it.

QUESTION #5. Explain briefly the compass.

ANSWER #5. A magnet free to turn, is called a compass. A compass placed in a magnetic field will turn until it points in the direction of the lines of force. Since the lines of force leave a magnet at the North pole, travel through the air space around the magnet, and enter the magnet again at the South Pole, a compass will point towards the South pole of the magnet. A compass is most commonly used to indicate direction. It is able to do this because the Earth is a large magnet, circular in shape, the flux leaving the Earth at the North pole and traveling uniformly over the surface of the Earth and entering again at the South pole. This seems in error as a compass will point towards what is commonly called the North pole but it should be remembered that this is the Geographical North Pole which is the Magnetic South Pole, not quite the same place but near the same place.

QUESTION #6. What is the right hand or thumb rule for wire? For coil?

ANSWER #6. The right hand or thumb rule for straight wire is as follows: Grasp the wire with the right hand so that the thumb points in the direction of the current, the fingers then will point in the direction of the magnetic field around the wire.

For a coil: Grasp the coil so that the fingers point in the direction of the current around the coil, and the thumb points to the North pole.

QUESTION #7. How can a coil of wire be constructed so it would be equivalent to a bar magnet?

ANSWER #7. A wire formed in the shape of a loop will have lines around it, all leaving on the same face and all entering it on the other face. The lines around several of these loops placed closely together would have no chance to fall between the loops and must continue around all of the loops before entering again. Thus it is seen that these lines act the same as the lines from a bar magnet. The coil (consisting of several loops closely wound) would act the same as a bar magnet, having a north pole and a south pole.

QUESTION #8. Explain the principles of electromagnets.

ANSWER #8. The core in the above described coil is air. If a core of iron were substituted for the air core, many more lines would be set up, on account of the low reluctance of iron and a much more powerful magnet would be the result. This is the principle of electromagnets. Coils of wire are would around a number of cores of soft iron. As long as there is no current going through the coil the iron is not a magnet. The face of the iron cores is brought into contact with pieces of iron or steel and the current is turned on. The iron cores now become strong magnets and will lift many pounds of iron or steel per square inch of core. As many as 100 to 200 pounds per square inch. This principle is also the basis of generators and motors. Coils of wire are wound around a soft iron core which is bent in a horseshoe shape. Therefore the magnetic circuit is entirely made up of iron except for the small space between the two poles, where the armature is inserted. Most of the armature is made of iron so that the magnetic is almost totally composed of iron. A very intense magnetic flux is set up which will induce a proportionally high EMF when the lines of force are cut by the wires of the revolving armature. This principle is also utilized for circuit breakers, etc., where the core is integral with the switch. A coil of wire is wound loosely around the end of the core and when the current becomes excessive in the circuit a strong magnetism results and the soft iron core is sucked up into the center of the coil, breaking the circuit. The strongest attraction exists when the center of the iron plunger nearly coincides with the center of the coil.

QUESTION #9. What is the unit of: magnetic current or flux? Magnetic pressure or magnetomotive force? Magnetic resistance or reluctance?

ANSWER #9. The unit of magnetic current or flux is "Magnetic lines of force" sometimes abbreviated "Lines" and is represented by the Greek letter "Φ" (pronounced phi). One line of force is equal to one maxwell.
The unit of magnetic pressure or magnetomotive force is the "Gilbert" and is represented by the letter "F"
The unit of magnetic resistance or reluctance is the "Oersted" and is represented by the script letter "$\mathcal{R}$"

QUESTION #10. What is Gilbert and ampere turn equal to?
The product of the number of turns in a coil by the amperes flowing through the turns is called the ampere-turns. A gilbert is equal to 0.4 pi or 1.26 times the product of the amperes flowing in the coil by the number of turns of wire in the coil.

QUESTION #11. What magnetic pressure would be set up if 4 amperes flowing in 750 turns of a coil wound on a wooden ring

ANSWER #11. Where:
F = magnetic pressure in gilberts.
.4 pi = 1.26
N = Number of turns in coil.
I = Amperes flowing through coil.

Formula: $F = 1.26NI$

Substituting: $F = 1.26 \times 750 \times 4 =$ <u>3780 gilberts.Ans</u>

QUESTION #12. Write Ohm's Law for magnetic circuits and give algebraic symbols and equations.

ANSWER #12. Magnetic Lines $= \frac{\text{Gilberts}}{\text{Oersteds}}$ or $\Phi = \frac{F}{\mathcal{R}}$

Oersteds $= \frac{\text{Gilberts}}{\text{Magnetic lines}}$ or $\mathcal{R} = \frac{F}{\Phi}$

Gilberts = Magnetic lines x Oersteds
or
$F = \Phi\mathcal{R}$

Where:
F = Magnemotive force = Gilberts.
Φ = Magnetic Flux = Magnetic lines.
$\mathcal{R}$ = Reluctance = Oersteds.

QUESTION #13. A magnetic circuit is composed of iron. The coil has 280 turns. When 3.6 amperes are sent through the coil a flux of 3000 lines is set up in the iron circuit. What is the reluctance of the circuit?

ANSWER #13. Formula: $\mathcal{R} = \frac{F}{\Phi} = \frac{1.26NI}{\Phi}$

Substituting:

$$\mathcal{R} = \frac{1.26 \times \overset{7}{\cancel{280}} \times 3.6}{\underset{75}{\cancel{3000}}} = \frac{31.752}{75}$$

$$= \underline{.4236 \text{ oersteds. Ans.}}$$

QUESTION #14. How many amperes must be sent through a coil on a wooden ring, in order to set up a magnetic flux of 600 lines? The reluctance of the ring is 16 oersteds. There are 280 turns on the ring.

ANSWER #14. Formula: $F = \Phi\mathcal{R}$

$$1.26\ NI = \Phi\mathcal{R}$$

$$I = \frac{\Phi\mathcal{R}}{1.26N}$$

Substituting: $I = \frac{\overset{15}{\cancel{600}} \times \overset{8}{\cancel{16}}}{\underset{.63}{\cancel{1.26}} \times \underset{7}{\cancel{280}}} = \frac{120}{4.41}$

$$= 27.2108 \text{ amperes.}$$

QUESTION #15. What materials are known as magnetic substances? Non-magnetic substances?

ANSWER #15. Iron and steel are known as the magnetic substances. Any substance other than iron or steel is known as a non-magnetic substance. There are a few exceptions nickel, cobalt, and alloys are magnetic to some extent though far less than iron or steel.

QUESTION #16. How is the reluctance of non-magnetic substances computed?

ANSWER #16. The formula for finding the reluctance of a magnetic circuit is similar to the formula for finding the resistance of an electrical circuit.

To find the resistance of a copper wire of any size or length, multiply the resistance of one mil foot of copper by the length in feet, and divide by the cross section area in circular mils.

To find the reluctance of a portion of any magnetic circuit composed of any material, except iron or steel, multiply the reluctance of a centimeter cube of air (which is the same as all non-magnetic substances) by the length of that part of the circuit in centimeters, and divide by its cross-section area in square centimeters. The reluctance of a centimeter cube of air is 1. The formula follows:

$$\mathcal{R} = \frac{1 \times L}{A}$$

Where: $\mathcal{R}$ = reluctance in oersteds.
L = length in centimeters.
A = area in square centimeters

QUESTION #17. Compute the reluctance of an air gap which is 1.4 centimeters square and 1.2 centimeters long.

ANSWER #17. Formula: $\mathcal{R} = \frac{1 \times L}{A}$

Since the area of a square is equal to the square of the length of one side:

$$\mathcal{R} = \frac{1 \times \overset{.3}{\cancel{1.2}}}{\underset{.7}{\cancel{1.4}} \times \underset{.7}{\cancel{1.4}}} = \frac{.3}{.49}$$

$$= \underline{.61224 \text{ oersteds. Ans.}}$$

QUESTION #18. How many ampere-turns are necessary to send 1000 lines through an air gap 0.26 centimeters long with a cross section area of 2 centimeters by 3 centimeters

ANSWER #18. Formula: $F = \Phi \mathcal{R}$

$$1.26 \; NI = \Phi \mathcal{R} = \Phi \times \frac{L}{A}$$

$$NI = \frac{\Phi L}{1.26A}$$

Substituting: $NI = \frac{\overset{500}{\cancel{1000}} \times \overset{.13}{\cancel{.26}}}{\underset{.63}{\cancel{1.26}} \times \cancel{2} \times 3} = \frac{65}{1.89}$

$$NI = \underline{34.3915 \text{ ampere-turns. Ans}}$$

QUESTION #19. How does the flux at the ends of an air core (long coil) compare in strength with the flux at the center?

ANSWER #19. Practically all of the reluctance offered to the flow of magnetic flux in a long coil (length at least ten times its diameter), the core of which is air or other non-magnetic substance, is that reluctance offered by the air or other non-magnetic substance within the coil. That is, the lines coming out of one end of the coil seem to take a path of zero reluctance through the air to the other end of the coil.

But all of the lines of force created by the coil, do not reach the end of the coil, about half of them leak out through the sides and return to that particular loop, so the flux at the ends of such a coil is one half of that in the center.

To find the flux at the center of such a coil, we merely follow the law for magnetic circuits: Lines of force is equal to the magnetomotive force divided by the reluctance. Since the magnetomotive force is equal to 1.26NI, and the reluctance of air or other non-magnetic substance is 1 times length divided by cross section area, the flux at the center of a such a coil is found by dividing 1.26NI by the reluctance of the air within the coil. To find the flux at the ends of the coil, divide the flux at the center by 2

QUESTION #20. What magnetic flux is set up in the air core (long coil) of 100 centimeters long and 1.5 centimeters in diameter, if it consists of 3500 turns in which 0.35 amperes is flowing? What magnetic flux is set up at the ends?

ANSWER #20. Formula: $\Phi = \frac{F}{\mathcal{R}} = \frac{1.26NI}{\frac{L}{A}} = \frac{1.26NIA}{L}$

Since a coil is circular, the cross section area in square centimeters is equal to the diameter squared times pi over 4 (.7854).

Substituting:

$$\frac{1.26 \times 3500 \times .35 \times 1.5^2 \times .7854}{100} =$$

$= \underline{27.2759 \text{ lines at center of coil.Ans}}$

$\frac{27.2759}{2} = \underline{13.6379 \text{ lines at ends of coil. Ans.}}$

QUESTION #21. How does the reluctance of iron and steel compare with the reluctance of non-magnetic substances?

ANSWER #21. The reluctance of iron and steel ranges from 0.016 to 0.00025, depending on the grade, which is much lower than the reluctance of air or other non-magnetic substances.

QUESTION #22. Why is it impractical to state the reluctivity of any particular grade of iron steel?

ANSWER #22. In a given sample of iron or steel, the composition and treatment of which is known, the reluctance will vary with the degree to which it is magnetized, therefore it is impractical to state the reluctivity of any particular grade of iron or steel.
Thus it is impossible to state a constant for use with the formula for finding the reluctance of iron or steel, as it is plain to see that the reluctance of magnetic materials from resistance of electrical conductors and even from the reluctance of non-magnetic materials.

QUESTION #23. What is the unit-piece magnetic and non-magnetic substance? Give explanation.

ANSWER #23. The unit-piece magnetic and non-magnetic substance is the centimeter cube. In computation of electrical resistance, a constant is used, being the resistance of one mil-foot (the unit) of that particular material. Similarly, in computing reluctance, we must know the reluctance of one unit of material, so we find the reluctance of one centimeter cube.

QUESTION #24. Explain briefly magnetizing-force. What symbol is it represented by?

ANSWER #24. Magnetizing-force is the magnetic pressure necessary to send a given number of lines through a centimeter of a magnetic circuit. The value of this magnetizing-force is stated in gilberts per centimeter, and is represented by the letter H. It can be compared to the voltage required to send a given electric current through a mile of wire of given dimensions, or in other words the voltage drop per mile of wire. So, it is possible to call the gilberts necessary to send a given number of lines through a centimeter of magnetic circuit, the magnetic pressure drop per centimeter of the material. To find the total magnetic pressure, if the magnetizing-force and the length of the circuit is known, multiply the magnetizing-force by the length.

QUESTION #25. What is the unit and symbol of the flux-density or degree of magnetization? Define the unit.

ANSWER #25. The unit of flux-density or degree of magnetization is the gausse, and is represented by the letter B. It is the value of the lines of force per square centimeter, corresponding to amperese per square inch cross-section of an electric circuit.

QUESTION #26. Explain briefly magnetization curves or B-H curves.

ANSWER #26. Since it is impossible to state a constant for the reluctance of a centimeter cube of a magnetic substance, on account of the change in reluctance due to the degree of magnetization, curves are plotted showing the actual number of gilberts necessary to set up a given number of lines per square centimeter in the material. We might plot these curves showing the value of the reluctance for any degree of magnetization, but it saves us much effort to have the curves plotted in gilberts per centimeter and lines per square centimeter, and, to find the reluctance it is only necessary to divide the gilberts per centimeter by the lines per square centimeter. (This gives us the reluctance of a centimeter cube of the material) So to find the reluctance of the magnetic circuit, we proceed as in computation of resistance of a material in an electrical circuit, ie., resistance of a milfoot of material, times the length of the material, divided by the cross section area of the material; similarly in magnetic circuits reluctance of a centimeter cube, times the length of the material in centimeters, divided by the cross-section area in square centimeters.

QUESTION #27. Show algebraic symbols and equations: for computing magnetic pressure, when the length of the magnetic circuit and gilberts per centimeter are known. For computing magnetic current or flux when lines per square centimeter in the material and areas of the material are known.

ANSWER #27. Formula:

$$F = HL$$

Where: F = Magnetic pressure in gilberts.
H = gilberts per centimeter.
L = Length of magnetic circuit.

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Formula: $\Phi = BA$

Where: Φ = Magnetic lines of force.
B = Lines per square centimeter, in gausses
A = Cross section area in square centimeters

QUESTION #28. Compute using B-H curve: magnetic circuit made up of annealed sheet steel pieces, having an average length of the long sides of 8 centimeters and of short sides of 4 centimeters. Each side is 3.5 centimeters wide. The pile of sheets is 2.8 centimeters deep. If 90,000 lines are to be set up in this core, how many ampere-turns are needed in the coil? Subtract 9% from the depth to allow for insulation between the sheets.

ANSWER #28. Area = 2.8 x .91 x 3.5 = 8.918 square centimeters.

$$\Phi = BA \therefore B = \frac{\Phi}{A} = \frac{\overset{45000}{\cancel{90000}}}{\underset{4.459}{\cancel{8.918}}} = 10091.958 \text{ gausses.}$$

H for 10091.958 gausses, annealed sheet steel, using B-H curve equals 2.5 gilberts per centimeter.

$$F = HL = 2.5 \times 24 = 60 \text{ gilberts.}$$

$$1.26NI = F \therefore NI = \frac{F}{1.26} = \frac{60}{1.26} = \underline{47.619 \text{ ampere-turns}}$$

Ans.

QUESTION #29. What are the relations of flux, reluctance and magnetic pressure in series magnetic circuits?

ANSWER #29. Series magnetic circuits follow the same laws as series electrical circuits. That is, the flux is the through all parts of the circuit, although the flux density of the parts may be different (If the cross-section area is larger in one place than another the flux density will be less in that portion); the reluctance of a series circuit is the sum of the reluctances of the several parts; and the magnetic pressure necessary to send a certain magnetic flux through a series circuit is the sum of the magnetic pressures necessary to send it through the several parts.

QUESTION #30. What is meant by series magnetic circuits? Parallel magnetic circuits?

ANSWER #30. A series magnetic circuit is one in which two or more reluctances are connected in tandem with each other and with the source of magnetic pressure, such as

ANSWER #30. Continued.

the armature, air gaps, and the iron core poles of a bipolar dynamo. In this case the armature has a reluctance, the air gaps have a reluctance, and the iron cores of the poles have reluctance. All of these reluctances are in series with each other and with the source of magnetic pressure. A bipolar dynamo (or a multipolar) also consists of a parallel circuit in series with the series circuit. This comes under the definition of parallel magnetic circuits.

A parallel magnetic circuit is one in which two or more reluctances are side by side or in shunt with each other and with the source of magnetic pressure The flux in a parallel magnetic circuit is the sum of the flux in the separate branches. The reluctance of a parallel circuit is the reciprocal of the sums of the reciprocals of the reluctances of each branch; and the magnetic pressure is the same in each branch.

The bipolar (or multipolar) dynamo described above, is a combination of a series and a parallel magnetic circuit; a series parallel circuit. In this case the North pole, the armature, the South pole and the two air gaps are in series and carry the whole flux. The top and bottom of the circular frame, connection the North pole with the South pole, are in parallel with each other and with the source of magnetic pressure, and since the reluctance of these two parts of the frame are about equal, the flux divides in two parts. The magnetic pressure necessary to force a flux through this combination is equal to the pressure necessary to force the full flux through the two poles, armature, and air gaps, plus the pressure necessary to force half this flux through either the top or bottom part of the frame, as the same pressure which force this half flux through either the top or the bottom, force the other half of the flux through the other parallel path.

QUESTION #31. What is meant by saturation point?

ANSWER #31. There are two stages of magnetization. The first stage is that during which it is comparatively easy to add lines of force to the material. The second stage is called the saturation point. The saturation point is that point beyond which it is usually unprofitable to magnetize the material because of the greatly increased difficulty in setting up lines of force.

This is evident from a B-H curve. Each curve has a peculiar shape. It is seen that in order to set up a few lines of force, a relatively small number of gilberts per centimeter is needed, but it becomes increasingly difficult to set up further lines. The point at which the curve bends into a nearly straight line running almost horizontally is the saturation point, and is the point beyond which it is unprofitable to magnetize a material.

QUESTION #32. Explain the relation of permeability to flux density.

ANSWER #32. It is possible to state the facts outlined in the previous question, in a different way. We might say that in the first stage of magnetization, as far as the saturation point, the reluctivity of a magnetic material is quite low, but beyond that point the reluctivity will increase rapidly until it is equal or nearly equal to the reluctivity of a non-magnetic material such as air. But it is customary to state it in terms of permeability, which is the reciprocal of reluctivity. Since reluctivty is the ratio of the pressure to the lines of force in a centimeter cube of the material, permeability will be the reciprocal or the ratio of the lines to the pressure. The value of permeability is the number of lines set up in a centimeter cube by one gilbert. If we let a symbol which looks something like a small u, stand for the permeability, and since the symbol for gilberts per centimeter (magnetizing force) is B, and the symbol for lines of force per square centimeter (flux density), the algebraic equation for permeability is:

$$u = \frac{B}{H}$$

Where:
- u = Permeability.
- B = Gilberts per centimeter.
- H = Lines per square centimeter.

QUESTION #33. How is the traction force of electromagnets computed?

ANSWER #33. To compute the traction force of an electromagnet, that is, the attraction or pull of the magnet upon a piece of iron or steel, the following formula is used:

$$F = \frac{8.94\ B^2\ A}{10^8}$$

Where:

- F = Pull of electromagnet in pounds.
- B = Flux density in air gap in gausses.
- A = Area of air gap in square centimeters.

QUESTION #34. Draw TL Transmitter.

ANSWER #34. See diagram on separate sheet.