Course Name: Design of Electric Motors

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Title: Electric Fields

In this lecture, we will discuss about the basic principles of electric fields and magnetic fields. So, the electric fields generated by the static charges and this thing is invented by Benjamin Franklin and magnetic fields created by the moving charges and invented by Orsted. So, if we will see the electricity and magnetism are the forces of nature and those are all are around us and we will see everywhere electric fields as well as magnetic fields. The examples if I will say mobile phones, computers, all electrical machines and electrical gadgets and after that cars, planes, everything. So, first I will start with electric fields. Before discussing about the electric fields, I will start with atom.

Atom is a particle, which consist of nucleus and electrons surrounded by the nucleus. So, this nucleus consist of protons and neutrons. Protons of positive charge and neutrons, there is no charge and electrons having the negative charge. If we will see the structure of an atom, this is the nucleus and surrounded by the electrons.

So, if I will consider an ideal atom, the charge with respect to the positive and charge with respect to the negative, both are equal or I can say number of electrons equals to number of protons. If I will add a electron to the ideal or neutral atom, then it will become a negative type of ion. If I will take out the electron, then it will become a positive ion. The magnitude of charge for positive charge as well as negative charge or I can say electron and neutron, sorry, electron and proton charge magnitude SUB_TEXT is equal and it is equal to the magnitude of proton and magnitude of electron charge is equal to 1.6 into 10 power minus 19 coulomb.

So, this is the atom background with respect to the charges, positive charges and negative charges. Suppose, if I will place the positive charges and negative charges near to each other, what kind of forces will be there and how its behavior. So, Benjamin Franklin in 1746, Benjamin Franklin gave the conclusions that positive charges will repel each other or same sign charges will repel each other either plus plus or minus minus and opposite charges like minus plus and plus minus will attract each other, plus

plus or minus minus repel each other and minus plus and plus minus will attract each other. So, based upon his findings with respect to the one fluid theory, he gave the conclusions that same polarity charges will repel each other and opposite polarity charges will attract each other. The one fluid theory is nothing but if I will consider an example and if we will discuss, so this is the glass rod.

If you rub with a cloth, the rod becomes the positively charged because it is losing the electrons, free electrons and the cloth which we are utilizing for rubbing the glass will gain the charges and it will became the negatively charged. He concluded that the number of electrons lost by the glass will be equals to the number of electrons gained by the cloth. So, that is nothing but the charge conversion principle. We cannot create the charge, but if we will say one is getting the positively charged, other is automatically getting negatively charged. In a complete isolated system, the total electrical charge will not change.

So, now we have concluded that the positive charges like similar polarity charges will repel each other and opposite polarity charges will attract each other, attraction and repulsion. So, what is the force of attraction? What is the magnitude? So, how to find this thing? So, in 1785, so in order to find the force magnitude, in 1785, Coulomb gave the relation for finding the force. Coulomb gave the relation for the force. Now, we will see what is the force magnitude or force relation. Let us consider the two charges like charge q 1 and charge q 2, which are separated by distance of r.

Now, we want to find the force acting on q 2 with respect to the q 1, that is force acting on the charge q 2 with respect to the charge q 1 and the unit vector r, I am considering to find the direction of the force and the force act repulsion force acting on the q 1 is nothing but F 2 1. The force acting on the charge q 1 with respect to the q 2, I am assuming that both are positively charged positive charges. Now, we want to find the force equation. The force F 1 2 is directly proportional to the charge magnitudes q 1 and q 2 and also proportional to the or proportional or I can say inversely proportional to the distance between the two charges, that is inversely proportional to the square of the distance between two charges. The final equation as per the Coulomb's findings, the force acting on the charge q 2 with respect to the q 1 is equals to q 1 and q 2 divided by r square into some coulomb constant and unit vector.

This will defines the direction and it is a coulomb's constant and this equation I am representing representing as 1 and this equation is highly sign sensitive. Equation 1 is highly sign sensitive. How it will be like? If I will consider charge q 1 and charge q 2, consider charge q 1 and charge q 2 and force here. If charge q 1 is positive and charge q 2 is positive, then the force is in the same direction of r. If charge q 1 is negative and charge q 2 also negative, then force is in the direction of same as the r, but if will change the sign like plus at this q 1 is the positive charge and q 2 is negatively charged, then here it is positive and here it is negative.

Then the force will be in a opposite direction with respect to the r. Similarly, if I will consider q 1 is negative and q 2 is positively charged, then the force is again in the reverse direction and we can see here. So, because of this analysis, the force equation is highly sign sensitive. Next, we will discuss about the coulomb's constant. k equals to the coulomb's constant and it is equals to 1 by 4 pi epsilon naught and the units are nothing but Newton meter square divided by coulomb's square.

So, how we can derive this units may be force equals to q 1 q 2 by r square. So, from this relation, we can get the units for coulomb's constant. These are the units. Here, epsilon naught equals to permittivity of free space. So, this value is equals to just bring all terms to this side and coulomb's constant is equals to the value is 9 into 10 power 9.

So, if I know the k value and just find the epsilon naught value, that will result 8.8 into 10 power minus 12 and the units will be just inverse to the coulomb's constant, coulomb's square divided by Newton meter square. Now, we have seen the force of attraction or force of repulsion with respect to the charges. Now, we have to see what is the electric field with respect to that particular charge. Now, I am again considering the same analysis.

So, I am considering a charge q and one more charge small q and this distance between these two charges is nothing but small r and a unit vector small r is the to represent the direction and the force is in this direction. The force acting on the test charge q with respect to the capital Q charge is nothing but capital Q comma small q is nothing but this one and here as per the coulomb's law force equals to capital Q into small q divided by inversely proportional to the distance between those two charges, right. That is r square into coulomb's constant into direction with respect to the unit vector. So, here electric field is nothing but the force per unit charge. This is the force per unit charge.

This is nothing but electric field. The electric field units are Newton per coulomb. These are the units and electric field is a vector and it depends upon the force direction. The direction of electric field depends on the direction of force. Now, we will see the positive charges, how the forces will be there and negative charges, how the force will look like.

The positive charge I am considering here, the force will be radially outward direction. If we will consider after certain distance here from here to here, distance is this much, right, small r. After this point, the distance is increasing, right. So, the force magnitude will come down. Similarly, if we will see the force after this distance r 2, this is the distance r 2 and earlier one, if I will consider r 1, this is r 2, then the force will come down further.

So, like this we can see that electric force with respect to the positive charge. The vector length represents the magnitude also here. This is with respect to the positive charge and negative charge is exactly opposite to this one. A negative charge if I will draw, then the force will be exactly opposite that is inward direction for the negative charge. Similarly, we can see that the force magnitude will come down with respect to the distance and so on.

We have represented here the electric forces, we will see the field lines with respect to the force. The force as well as electric fields both are in the same direction as per the equation what we have discussed earlier. Now, we will see the electric field fields, how it looks like. So, electric fields also same as the force, just it is, this is the negative charge and if I will plot the electric field lines. So, for positive charge it will be radially outward direction and the tangent to this flux lines or electric field lines is nothing but your force and for the negative charge the field lines will be inward toward the charge.

So, these are the electric field lines. We can see that from these pictures or from this analysis, the electric field lines are formed or created by monopoles. There is no dipoles, electric fields are the monopoles. If I want to create the electric dipoles, we have to place the same magnitude of positive charge and same magnitude of negative charge with some distance, if I will keep between the two charges, then we can create the electric dipole. The field lines with respect to these two charges will be in this manner.

This is the electric dipole formation with respect to the positive charge outward direction with respect to the negative charge inward direction. This is the electric dipole. Now, if I will consider the different type of magnitudes of the electric charges, let us consider here plus 3 charge and minus 2 charge. This is plus 2 charge and minus 2 charge. So, how the field lines look like? So, in order to find the field lines, just consider a test charge.

Assume that one test charge is here. So, with respect to the distance, which one is near? This is the test charge Q. So, with respect to the negative minus 2, it is closer. So, minus 2 is the dominant. So, we will see the attraction and if it is far away test charge, then as compared to the negative minus 2 and plus 3 is more dominant, we will see the outward direction.

So, in between, we can say the electric field is 0 at some particular point. So, if we will draw the flux lines with respect to this plus 3 and minus 2 charges like unsymmetrical dipole, the plus side, the flux lines will be outward direction and minus side, it will be inward and with respect to our test charge analysis, the flux lines are coming inward with if the test charge is here and if the test charge is here also, it will be inward. After certain point, the electric field will be 0. After this point, all forces will be outward direction, electric forces, even flux lines also.

So, we will see in this manner. These flux lines will not intersect and it will flow in this manner and the direction will be from plus charge It will go out and from minus charge, it will come in. Here, electric field is 0 at some particular point, where you will not see any no flux lines and after that, if I will place a test charge far away, it depends upon the plus 3 charge dominance, we will see the flux lines are flowing out. So, these are the basic principles with respect to the electric field lines. Now, we want to find what is the electric flux? What is the magnitude? If we know the electric field and if we know the charge, how to find the electric flux? We will discuss that thing. So, Gauss law gives the relation between the electric flux and electric fields and the Gauss law states that the total electric flux coming out from a closed surface or an any arbitrary surface is proportional to the electric charge enclosed by that particular surface.

The explanation of the Gauss law, we will discuss now. Let us consider the electric flux lines are flowing in this manner and consider an arbitrary surface in this fashion, arbitrary surface or any closed surface. In that, consider a small element dA. So, with respect to the flux line direction, the electric field direction also in this manner and then, unit normal to that plane or electric field is n bar n cap.

I can say that is the unit vector. The angle between e and unit vector is theta. So, the Gauss law gives the relation between electric fields and electric flux lines and the change in flux is nothing but E dot n cap into dA with respect to the area and electric field. Generally, n cap and dA represented by dA bar as a vector and E also a vector electric field E dot dA. This is the change in electric flux. If you want to flux, if you want to find the electric flux with respect to the complete entire surface, then we have to integrate it d phi e equals to integral of E dot dA.

This is the equation which we will utilize it to find the electric flux flowing through a complete closed surface. That is equals to the summation of charge enclosed with respect to the permittivity epsilon naught. This is the equation for electrical flux equals to E into A. The Gauss law of electric fields is nothing but flux equals to total charge enclosed with respect to the permittivity. The derivation with respect to the charge over the epsilon naught, we can do it offline based upon the by considering the sphere as an example.

Thank you. With this, I am concluding the electric fields.