Advanced Electric Drives
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Lecture - 22

Hello and welcome to this lecture an Advanced Electric Drives, in the last lecture we are discussing about the field structure with permanent magnet, the field structure of a permanent magnet DC motor. The field is usually stationery in a DC motor as we know, the field is stationery and for a permanent magnet DC motor the field is permanent magnet. So, we have seen various classes of magnets, like alnico magnet, ferrite magnets samarium-cobalt or real earth magnets, and also new barium iron boron magnets.

So, we were just discussing the field structure with the permanent magnets, let us first see the field structure with ferrite alnico magnets.

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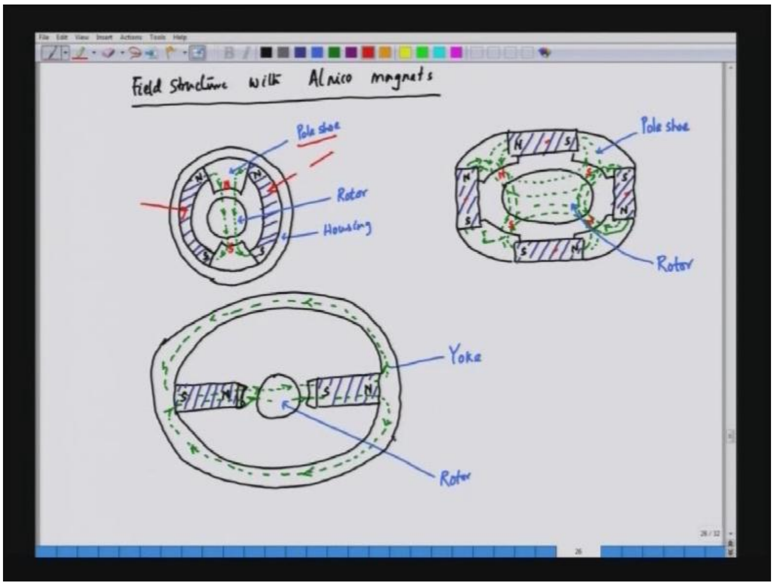

This is the field structure with alnico magnets, and as we know that we need very thin and long alnico magnets. Now, these are magnets that is phrase in the field, source of the magnets, this magnets are thin and long we can see here, we have a north pole and we have a south pole here, and this is pole shoe to facilitate the pole flow of the flux. Similarly, we can have these for a two pole structure we have one north pole here, and one south pole here ultimately.

So, this is basically two pole structure know, if we see for a 4 pole structure, the structure will be like this with alnico magnets. Alnico magnets are thin and long magnets, so this is 1 magnet, 2, 3 and 4, and these 4 magnets in total result in 4 poles, 2 north poles and 2 south poles. This is the north pole, which is produce by these 2 north poles, and we have the south pole which produced here, and then we again have a north pole here, and again we have a south pole here.

So, this is basically an example of alnico magnets with will result in 4 pole structure, now we can see another configuration also like, we have magnets which are arranged like this. And this is the north pole, and this is south pole structure we have the yoke, the pole shoe and this is the rotor core, and this is a two pole structure, now similarly we can also thick of a 4 pole structure corresponding to this, where we have 4 thin and long magnets.

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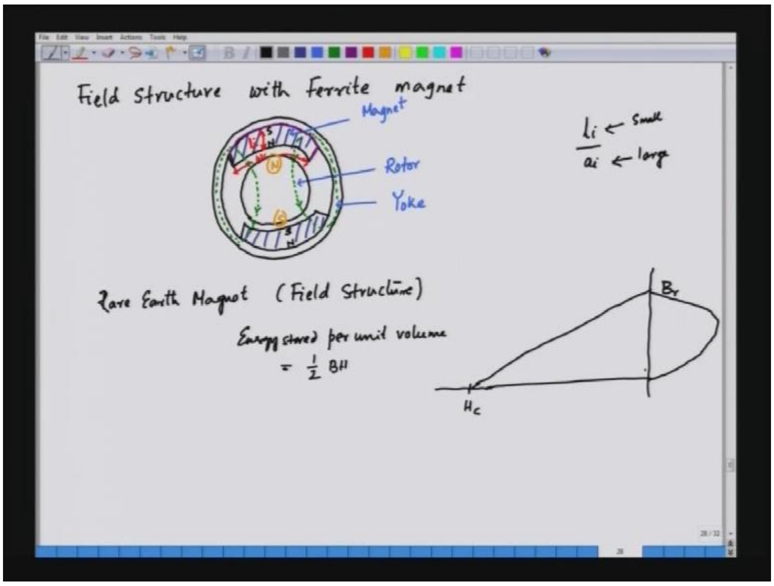

Now, if we go to ferrite magnets, we have all ready seen there for ferrite magnets we need thin magnets, but with large width. We have this l by a ratio l i by a i and for ferrite we need small l and large area cross sectional area, so l i is the length of the magnet, and a i is the cross sectional area of the magnet. Now, we see here that this is the arrangement with the ferrite magnet, this is l i the length is small, and the width is considerably large this is basically the width of the magnet w i, and hence we will have a large cross sectional area.

So, we have a thin magnet with large cross sectional area, which is the requirement of ferrite magnet. And this is for a two pole structure, we see here that this structure will resulting into one, ultimately one north pole here, and then south a pole here we have the yoke and the yoke usually made of soft tailor festally fire, the flow of flux. Similarly we can think of the 4 pole structure, the most expensive magnets are the samarium-cobalt or rare earth magnets.

Because, they have large b r and large s c we are already seen in the last lecture that if we see this rare earth magnet. So, we are talking about the field structure, so field structure with rare earth magnet, so we have large the residual flux, and also large cohesive force. So, these magnets are expansive magnets, and they are use for those applications where we need very compact motor because, of large b r and large s c essentially what we have, we have large energy store.

Because, energy stored per unit volume is half into B H we also know that energy stored for unit volume is equal to half B into H. So, this will be resulting in a B H product curve like this, and it is sufficient to have a very thin magnet, yet have a considerable amount of flux density. So, essentially the ferrite core the samarium cobalt magnets or rare earth magnets, they are very thin magnets and with thin magnets also we can produce large flux density. So, we will see an example of the field structure with samarium-cobalt magnet.

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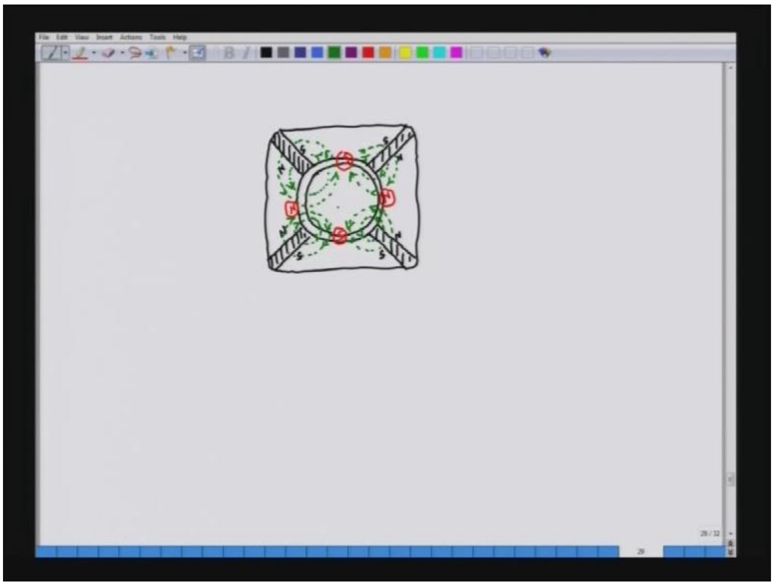

So, this is the field structure we have with the samarium-cobalt magnet, with drawing a 4 pole structure, this is the rotor. We have the stator inner surface, and the magnets are placed here, this is one magnet, this is other magnet, this is third magnet and this is the 4th magnet. So, we can have these 4 magnets here and the polarities of the magnet can be suitably arranged, so for example, this could be a north pole, this could be a south pole, so this is the magnet.

Similarly, this is a magnet and we can have a north pole here, and a south pole here, again we have a magnet here, we have the south pole here, and then we have the north pole here, we have a another magnet in this case. So, thin magnet north pole and south pole, as a result here we have 4 poles here, we have 4 magnets which we will result into 4 poles 2 north poles and 2 south poles. We can see the flux lines, the flux lines will be like this that here is a magnet, so we have north pole, flux line should be coming out of the north pole and entering the south pole.

So, this is the flux lines coming out of the north pole and entering the south pole like this, then we can have another flux lines which is coming out of this magnet. So, this is another flux line an entering here, for this we can have the flux lines north pole, and then south pole. Similarly we have the flux lines here, north poles and south pole, here also we have the flux lines, and this is the north pole and this is a south pole.

So, ultimately we have here 2 south poles and 2 north poles, so this is the south pole, so we have the south pole which is created here, and this is also south pole. Because, the flux is entering, so we have a south pole here, and here we have north pole because, the flux is going out, here also we have a north pole. So, fluxes will be going out this north pole like this, and fluxes will be entering a south pole like this, here also we have south pole flux will be entering and we have north pole here flux will be going out.

So, we have seen an example of the field structure of DC motor have been samarium-cobalt, now in this case since the samarium-cobalt magnet is having large energy density, we can have very thin magnets. And hence the structure or the size of the motor can be made very compact, without compromising with the power, so we can have very high power to weight ratio the weight and volume can be reduced, and the power can be increase by having samarium-cobalt. The application of such kind of a motors is first place application, where we have constant of space constant of weight.

So, we can a have very heavy material there, we cannot have a motor which is heavy, so first place application for aerospace application, we go for motors permanent magnet motors having samarium-cobalt magnets. So, with this is a we have seen actually the field structure of a permanent magnet DC motor, the DC motors the conventional DC motors as we understand, has an armature and a field winding. And the armature has commutated and brushes, and we have fix and contact with the commutated and brushes.

And hence we has sparking at the brushes, we can also have motors without any brush, and those motors are call brush less DC motors. So, we will see the structure of permanent magnet motors, which are use for brush less DC motor and permanent magnet synchronous motors.

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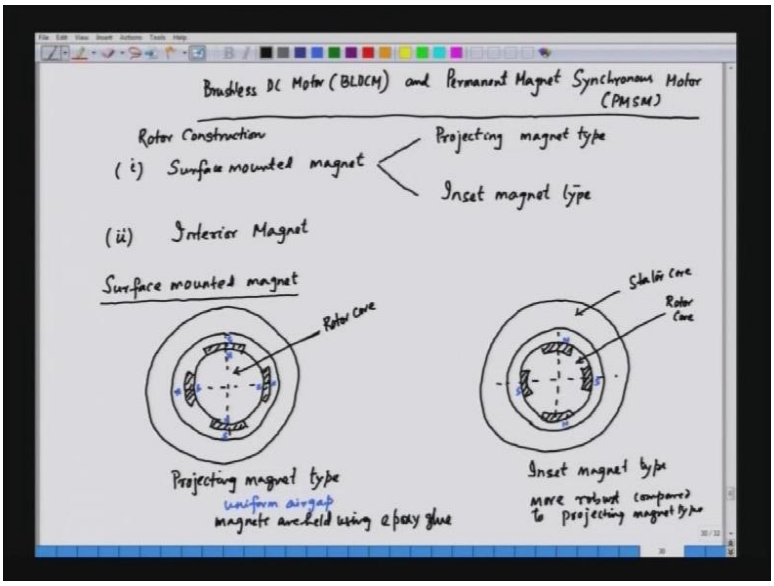

(12:05) So, our next discussion is basically on Brush Less DC Motors, so this is abbreviated as BLDCM and Permanent Magnet Synchronous Motor, and this is abbreviated as PMSM. Now, we can classify this motors base on the structure of the rotor, now both these brushless DC motor and permanent magnet synchronous motor, work on the principle of synchronous machine. In the synchronous machine we know, the speed of the rotor is synchronous speed, the rotor will not drawn at any other speed than the synchronous speed.

So, the principle of brush less DC motor and PMSM motors, are essentially the principle of synchronous motor. So, based on the rotor construction we can divide these motors, so we will see the various classification of this motor based on the rotor construction, so we can classify this motor, as number 1 is the rotor construction base on the construction of rotor. We can classify this motor is surface mounted magnet, and number 2 is interior magnet.

As we know that in a synchronous machine the field winding is usually the rotor, the rotor is the field winding, the stator carries the armature winding. Now, the field winding is not the conventional wound field winding, the field winding is replace by permanent magnet, it could be 4 pole, it could be 2 pole, it could be 6 pole ultimately the field winding on the rotor is a permanent magnet. Now, based on the housing of the permanent magnet, we can say whether the rotor is a surface mounted magnet rotor or a interior magnet rotor.

Surface mounted means, the magnet is mounted on the surface of the rotor, and again this surface mounted motor is classified in 2 categories. We can have the projecting type magnet or projecting magnet type and inside magnet type, let us see the structure of surface mounted rotor. So, we have the rotor here, and then in the rotor what we have done this is 4 pole structure, the magnets are mounted on the surface like this, so these are basically the magnets, and the stator is around this rotor, so we have the stator structure like this.

So, this is a projecting magnet type motor, so we are talking about the surface mounted magnet. So, here that is a we have north pole here, and a south pole here, so ultimately we have the north pole, which is seeing the stator, and we have the south pole here and again we have north pole, and we have south pole. And the rotors are fix to the I mean the magnets are fix to the rotor using epoxy blue.

Now, this is very easy to construct we can have the rotor, the rotor is basically soft iron core this is the rotor core which is soft iron core. And the magnets are group to the rotor using epoxy blue, now this construction is quiet simple, but the motor is not robust because, the magnets are group to the rotor using epoxy blue. So, you can have a very high speed, we have a very high speed there will be high centrifugal force the magnets may fly off of course, this is use for very low speed application where, we can up to have a such kind of construction, this is one type of construction here.

The advantage of this type of construction is this, that the air gap is uniform we can see that the rotor and the stator is having uniform air gap. So, this is for projecting magnet type, and the characteristics of this is uniform air gap, and the magnets are held using epoxy blue not very robust. Now, if we one to go for a little robot construction, what we do there is that magnets are buried or pressed inside the rotor, and that is call a inset permanent magnet structure.

So, we will see an inside permanent magnet structure, where we have the rotor here, and we can construct a 4 pole structure. Where we have the magnets are put inside the rotor like this, they are not projecting they inside the rotor, and this is why this motor is call in set type surface mounted motor. So, this is the magnet, these are the permanent magnets which are inside the rotor, this is the rotor core and the stator structure is here, this is the stator structure which is around the rotor.

And similarly, we can have a north pole here, south pole here, north pole and south pole the magnets are arranged in such a fashion that we have 2 north poles, and 2 south poles. Now, here the magnets are inside the surface of the rotor, and they are held by means of a torque tube, so that they should not fly off, and this kind of construction is more robust than projecting magnet type, and this construction is call inside magnet type.

Now, we will see the example of some very typical low cost brushed DC motor, where the rotor construction is inside magnet type, where the magnets are placed on the rotor and they are held, so that they should not fly off. Now, here the advantage is that more robust compare to projecting magnet type, this is the stator core, and the stator and the rotor are made of a sub talon their laminated structure.

And inside magnet type rotor or permanent magnet brush less DC motors are prepared for many applications, now these are surface mounted type of main magnet motors. Now, we can have another class of a motors in which the magnet is boride inside the rotor, and those class of motors are call interior permanent magnet motors.

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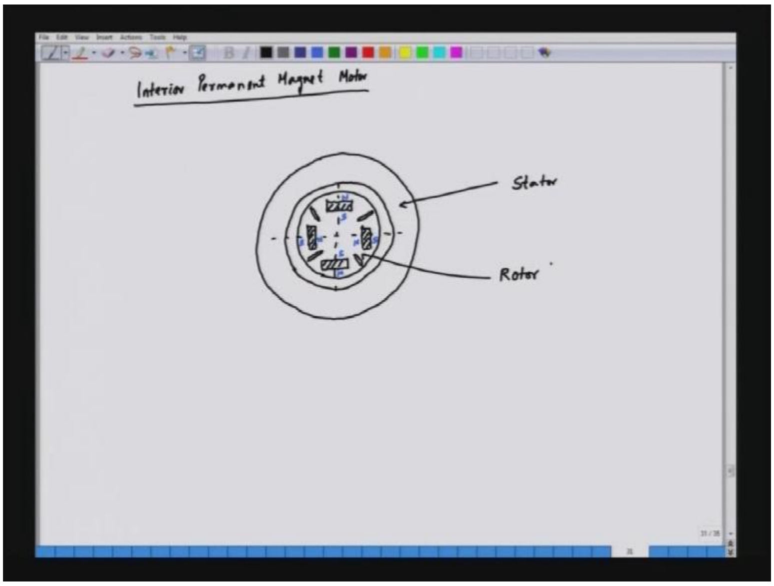

So, we will see some example of interior permanent magnet motors, so we have the rotor here, and we are again talking about a 4 pole structure, and equivalent 4 pole structure. So, we have the magnets which is buried inside the rotor, we can see here the magnets are not on the surface, but they are inside the rotor, so these are the magnets and we have some air gap which is created here. So, that the flux will not short circuit in the rotor, so this is north pole, and we have a south pole here, again we have a north pole, and again a south pole we have the stator structure.

So, this is the stator and this one is the rotor and this calls of motors which are interior permanent magnet motors are very robust, they are use for high performance application. The speed can be very high because, the magnets are well inside the rotor there is no question of having centrifugal force, and the magnets will fly off as we have seen in case of projecting magnet type rotor. So, the magnets are covered within the rotor and hence, the rotor structure is very, very robust this kind of motors are preferred for automobile application and for traction applications.

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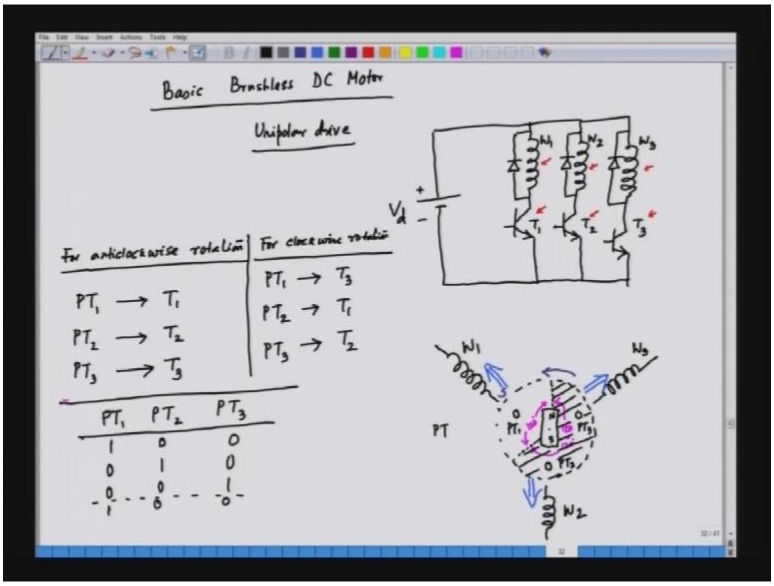

So, with this let us move forward to a basic structure of a brush less DC motor, we will see the operation of a brush less DC motor basic brushless DC motor. Now, in a basic brush less DC motor, we have 3 phases in the stator, and the rotor is a permanent magnet rotor. So, what we have in this case, we have 3 phases in the stator and the phases are connected to 3 transistors like this, so these are the 3 phases of the stator we have the transistors here, and these are the 3 windings in the stator.

And there is anti parallel diode here, which will freewheel the inductive current and this is connected to a DC source this is V d. So, the when the transistor is turned one of the phases is energized, we can call this phases as a, b, c or w 1, w 2 and w 3, we have 3 different phases. And how are they arranged, they are arranged in the following way this is the structure we have, we have the rotor and the phases are arranged in the following fashion one winding is here, other winding is 120 degree away from this, and the third winding is again 120 away from the other winding.

So, this how the windings are arranged, so what we are seeing here we have got 3 different windings. And 3 windings represents 3 phases of the motor, one phase is w 1, the other phase is w 2, and the third phase is w 3 and they are phase shifted in space by 120 degree. So, we can call this to be w 1, this to be w 2, and this to be w 3 and they are connected to this transistor and the transistor is T 1, this transistor is T 2, and this transistor is T 3.

Now, what about the rotor, the rotor is having a 2 pole structure say for example, we can consider the rotor to be a magnet, and the magnet is having just 2 poles in the following fashion. So, in the rotor we have a magnet and the magnet is having 2 poles, one north pole and other is south pole all right. And in this case also what we have here, we have two, we have three optical encoders, we have an optical encoders and we have 3 photo sensors and we have 3 light sources.

So, these are basically the photo transistor PT and we have here P T 1, P T 2 and P T 3 and this is arranged in the following fashion we have an optical encodes which is realize like this. So, this had ritual is the basically the sorter or the o peg region, and the region which is clean that region is the transparent region. So, we have 3 photo transistor and the other side we have the photo source, so whenever the o peg region is encounter, the photo transistor does not given a signal or the signal is 0.

And when the transparent region is encounter, the light passes and the photo transition the corresponding photo transition we give high signal or a one signal. So, as the rotor rotates the 3 photo transistors will give us the signals, sometime the photo transistor will be giving us high signal, and sometime photo transistor will be giving us a low signal. Now, let us assume that whenever a winding is excited, how do excite the winding we can excite the winding w 1 by turning on T 1.

Similarly, we can excite the winding w 2 by turning on T 2. We can excite the winding w 3 by turning on T 3 we have three different windings. And the corresponding transistors has to be turn on to excite the winding, whenever a winding is excited a current is pass through it. And when a current is pass through the particular winding, the winding produces a south pole, and hence at the movement let us say we excite w 1.

So, if we excite w 1 what we have here is the following a south pole is stated here, now in a south pole is stated here this north pole is attracted towards south pole, the rotor will rotate in the anti clock wise direction like this. And when this rotates this will be align along w 1 after sometime, the north pole of the rotor will be align along w 1. And then P T 1 will be covered, the photo transistor 1 will be covered the o peg region will come and the photo transistor 1 will be covered, and hence we will have P 2 will be lighted.

So, we have structure like this for anti clock wise rotation, for anti clock wise rotation we give the following signals, what we do here the photo transistor one P T 1 feeds the transistor 1. And P 2 feeds the transistor 2, and P T 3 feeds the transistor 3, now we see here that if P T 1 feed transistor 1, w 1 is excited. And when w 1 is excited a south pole is created and it attracts the north pole of the rotor, rotor rotates in the anti clock wise direction, now after sometime P T 1 will be covered, and P 2 will be lighted.

And hence the poles will be applied to w 2, and then after sometime P T 3 will be lighted and hence, what we see here the rotor will continuously rotate in anti clock wise direction. So, they has to be a position encoder like the present case, we have 3 photo transistor and we have o peg and partly transparent. And in this case, we make this 120 degree this is 120 plus 120, so that is make 240 and this is 120, so when we make this gives 240 will be o peg, and 120 will be transparent.

So, this could pressed on to the rotor, so it is glued on the magnet, the rotor is basically a magnet having a south pole and a north pole, so what we do we make this disk wheels having 240 o peg region, and 120 transparent region. And we glue this to the rotor, so that this also rotates along with the rotor, so this disk this o peg and transparent disk is glue to the rotor, and it is rotating along with rotor. So, as the rotor rotates the disk also rotates, so as a result sometimes P T 1 will be high, P T 2 will be high after sometime and P T 3 will be high.

So, in fact, if we try to see the signal in this case, the signal will changing the following fashion, say P T 1, P T 2 and P T 3 how do the signals change. Initially we had 1 0 0 at this present situation P T 1 is lighted, so we have 1 for P T 1, P T 2 and P T 3 are 0 0. Similarly after sometime, P T 1 will be covered and P T 2 will be lighted, so 0 1 0 then after some time P T 1 and P T 2 will be covered, and P T 3 will be 1, so 0 0 1. And then after that the sequence repeat it will be again 1 0 0, so essentially as the disk rotates the photo transistors will be giving a signal, and one of the photo transistor will be 1.

And therefore, one of the winding will be excited, and when one of the winding is excited the across sun force is produce, the rotor is attracted towards the stator magnetic field. And when the rotor reaches that magnetic field, the magnetic field shifts to the other phase, so continuously the rotation because, the magnetic field shift from phase w 1, 2 phase w 2, 2 phase w 3. In fact, when we excite w 1 we have south pole produced here, so we have field structure like this, the south pole is produced like this.

And then after sometime w 2 is excited, so we have the field which is produced is along w 2, similarly after sometime field 3 is the w 3 is excited. So, the field is along w 3, so we have continuous rotation of this field, the field move from w 1 to w 2 to w 3 and the rotor follows this particular field, and this is the principle of brush less DC motor very simple brush less DC motor. Now, if we want to change the direction of rotation, we can also change the direction of rotation.

So, we will see that for clock wise rotation we can just change the connection, earlier what we said that output of P T 1 should be feed to transistor 1. Similarly output of P T 2 will fed to transistor 2, and output of P T 3 will be fed to transistor 3, now here we will make a little difference. The difference is this output of P T 1 is fed to transistor 3, and output of P T 2 will be fed to transistor 1, and output of P T 3 will be fed to transistor 2. So, we were just seeing the operation of a simple brush less DC motor, we have 3 windings in this case and we were discussing the clock wise rotation.

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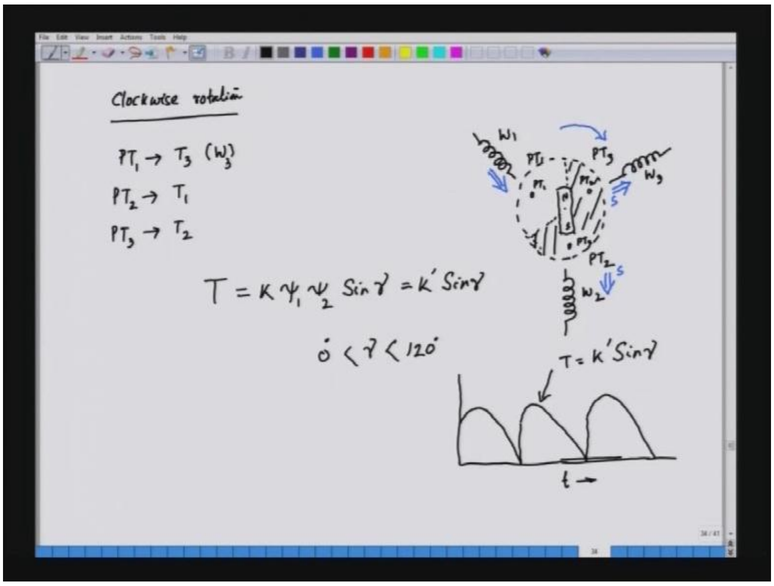

In the clock wise rotation the photo transistor will be connected like this that P T 1 will be connected to T 3. So, it means in the present condition, we have this is P T 1, P T 2 and P T 3, so this is the photo transistor 1 and this is the photo transistor 2, and this one is photo transistor 3. So, when P T 1 feeds T 3 or w 3 here, correspondingly the winding 3 is excited, so we will have a south pole here.

So, when we have south pole in this case, this north pole is attracted towards the south pole. So, the rotation will be in the clock wise direction, so the rotor will rotate in the clock wise direction like this, similarly P T 3 is feeding w 2, so the field will be moving from this position to this position. And then after sometime the field will be moving to w 1 to this position, and hence we have continuous rotation which is in clock wise direction.

Now, this is a simple principle of a brush less DC motor, now this brush less DC motor is use for very inexpensive application applications. For example, the fans in a computer power supply all of us are familiar with the computers, in the computers we need a fan and the fan is basically for the cooling purpose. Now, this is an example of a computer fan, we can see here the this is a computer fan and this is a brush less DC motor because, this fan is going to run for years together without getting damaged.

So, if we go for a simple DC motor having brushes and commutates, we have fictional contact there the contact will develop problem. And once the fan stops the cooling will also stop, so this fan is suppose to run industry environment without any problem because, it does not have any brush. Now, if we see the back side of this we have the rating of the fan, on the rating source that it is a 12 volt fan, approximately 0.14 ampere or 140 mile ampere.

So, roughly it is close to let us say 2 what, so it is basically a 2 volt fan, which is use for computer power supply. Now, we can open up this fan and see the structure inside the fan, these are basically the connectors for connecting the DC power supply, which is plus 12 volt. Because, in computers we have DC power supply, and if we remove this inside region we will see that the fan is the rotor.

Here, the rotor is basically surrounding the stator, so these are the magnets the magnets are placed inside this they are boride here. So, we can have south pole, north pole, south pole, and north pole inside this, and this is field to rotate we have shaft here, and the shaft can go in to this and this can rotates freely. And if you remove this, this shows the structure of the stator, now we have seen that the stator in this case has concentric winding. You can see here that, we have all these windings here the copper windings are placed here.

And here for example, here we have 4 windings 1, 2, 3 and 4, and this windings are excited depending upon the rotor position. The rotor is the magnet, this is the magnet the magnets are arranged inside this, and this is the stator which is inside and the rotor is free to rotate. So, the stator is excited as we have seen that we have a photo encoder, similarly the rotor position is changed and these windings are excited, may be w 1, w 2, w 3 and w 4. And since we have 4 windings, we must be adding 4 transistors each winding is excited by single transistor.

So, in this case we are expecting that these windings should be connected to at least 1 transistor. And if you see very closely there is a printed circuit board here, which is attached to this stator, it is stationary and connected to the external power supply, so this is the printed circuit board. And the printed circuit board there are very less components, you can see there is a single transistor structure here, and these are got 4 legs.

These 4 legs could for the 4 windings, since we have 4 windings this basically the switch is the power switch, and this will be switching the current to all these 4 windings. Since we have the DC power supply, the DC power supply is given here, so we have a switch and then the rotor position is same here by hall effect sensors, the rotor position can be sense by an optical encoder, this can also be sense by hall effect sensors. Because, hall effect sensors are the sensors, which can detect the field position or the position of the flux lights.

So, here the hall sensors are mounted in this case, and hall sensors along with the stator mount it on the stator, sensors the position of the magnets in the rotor. And accordingly the windings are switch on and off, when the windings are switched here, the field is produced in the stator, and when the field is produced in the stator that is a torque production. And as the rotor rotates the field goes on shifting, and hence there is a continuous rotation.

So, this is a very inexpensive motor, but this is an example of a brush less DC motor we do not have any brush, we can see here this structure does not have any brush. So, the disadvantages associated with the brush and compotators, and done away with, so this is an example of a low cost brush less DC motor, as we are discussing. And in this case the rotor and the magnet position are detected using hall effect sensors, now if we come back to our discussion here, as a rotor rotates the stator field goes on shifting.

So, as a result we have drawback and the drawback is torque pulsation, now if we see the expression for the torque, torque is equal to k psi 1 into psi 2 into sin of the angel with between them. So, we can say sin of gamma, so psi 1 could be the stator flux, psi 2 could be the rotor flux and gamma is the angle between psi 1 and psi 2. Now, in this case you can see that, when the winding of the stator is switched done, the angle is approximately 120.

So, in fact, gamma in this case varies from 0 to 120 all right, so we have the expression for the torque, and gamma is not constant we are having any constant angle. In each revolution there are 3 switching's because, we are having 3 transistors, and the torque is proportional to sin gamma, and gamma continuously changes 0 degree to 120 degree. And hence, the torque where is as follows, so if we see the plot of the torque in this case as the time progresses, we can see that torque will change in the following fashion, it is varying as sin wave, but varying like this.

So, this is basically the torque and torque is equal to k prime sin gamma, we can say this is equal to k prime sin of gamma. And gamma is not constant gamma is in fact, changing and also gamma changes the torque is going to change, now what is the effect of that although we have average torque. We can say that we do have average torque here, and hence the rotor rotates, but never the less the torque fall sets.

That is torque fall session may not be dangerous in a small motor like this a fan, fan drive, but this could be on acceptable for high performance application like a traction or an automobile applications. And hence this class of motors are use for low cost applications like fan applications, where the torque re pulls or a torque fall session can be tolerated. Now, we will go one step ahead, now here we have a structure like this, we are exciting this from a single DC supply.

And the current in every winding is in one direction, we also call this to be a unipolar drive, unipolar drive means the current in every winding is in one direction and 1 winding is excited for 120 degree, and it is only in one direction. So, sometimes if you have 3 windings, and only 1 winding is excited the motor is not fully utilized.

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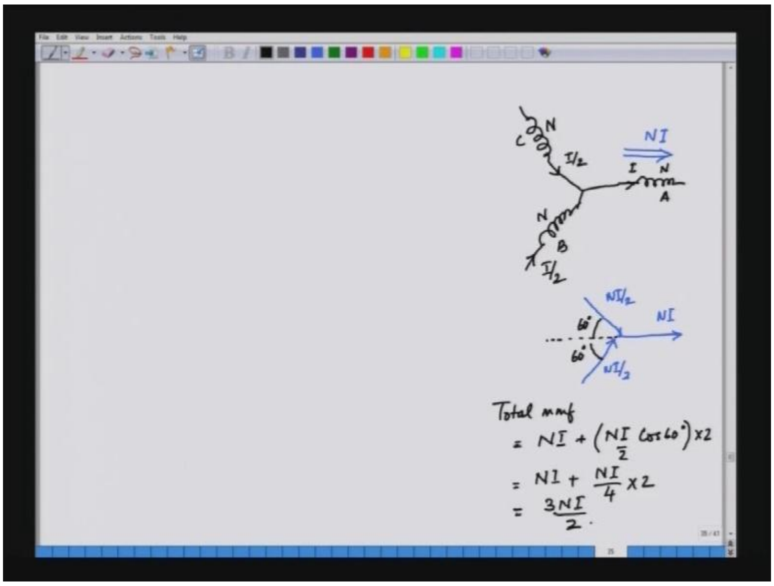

Say for example, if you have a structure in which we have the windings and we excite only one winding. So, we only pass current to only one winding, this is a number of terms here N, and this windings phase B and C, if you say A, B and C, phase B and C are not exited. So, if phase B and phase C are not excited the mmf in this case is N into I, what we obtain here is the mmf, the mmf is in this direction and that is equal to N into I. So, this is a unipolar drive where only one winding is excited at a time and this results in low torque production.

On the other hand, if we excite all 3 windings and have facility, so that each winding is carry bidirectional current, both positive and negative, we could have higher torque production. Say if we connect this, and connect this in star like this and pass current to this winding also, we can have say I by 2 here and I by 2 here, and this is the same number of terms N and N. So, in this case we have N I produce by phase A, N I 2 produce by phase B, and N I by 2 produce by phase C.

So, we have excited 3 windings right now, and each winding 1 winding is carrying I current, other winding is carrying I by 2 and I by 2. And hence the total mmf in this case can be calculated here, the mmf be vector this is 60 degree, this also 60 degree, so we can say there is a total mmf is equal to N I plus N I by 2 into cos of 60. And since we have 2 other phases multiply by 2.

Now, cos 60 is half, so if we if we see here that cos 60 and cos 60, so we have one force in this case. So, N I plus N I by 4 into 2 and that is 3 N I by 2, so what we see here is that, when we excite all 3 windings we get an mmf that is 3 by 2 times of N I, compare to whenever we exciting a single winding. So, it is always beneficial to have a brush less DC motor, where we can excite all 3 windings simultaneously and that possible in a bipolar drive, so we will see the structure of a bipolar drive.

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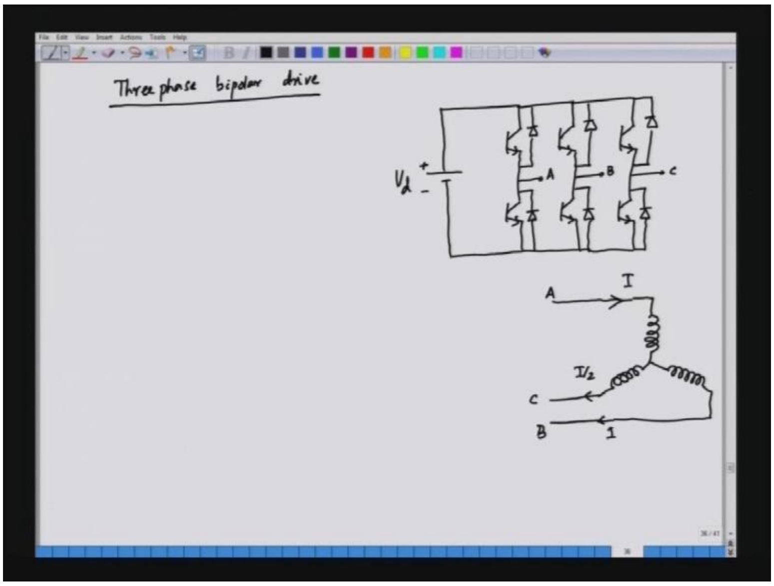

So, in a bipolar drive we are talking about a 3 phase bipolar drive, what we have here is the following we have a inverter. A inverter has got the transistors 6 transistors here, and these are the anti parallel diodes, so we have the 3 terminals which are coming out in this case are connected to phase A phase B and phase C of the motor. This is the DC voltage, and the motor has got 3 windings, phase A, phase B, and phase C, this is A phase, this is B phase, and this is C phase. So, this A, B, C terminal of the windings are connected to A, B, C terminals of the inverter.

So, here we operate this inverter in 180 degree mode, in this case is the current enters in to 1 winding I, this comes out of the other 2 windings I by 2 and I by 2. So, in this case we ultimately have a mmf, which is 3 by 2 times N into I which is higher than a unipolar drive. So, we will be discussing in the next lecture about a bipolar drive, and the associated control structure with a bipolar drive, and how to have same the clock wise rotation, and also anti clock wise rotation.