Fundamentals of Electric Drives

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Lecture – 07

Field Control of Series Motor, Motoring and Braking of Separately Excited and Series DC Motors

Hello, and welcome to this lecture on the fundamentals of electric drives! In our previous session, we discussed the various methods for controlling the speed of a DC motor, specifically focusing on voltage control and resistance control. Today, we will build upon that knowledge and explore a new technique: speed control through field control.

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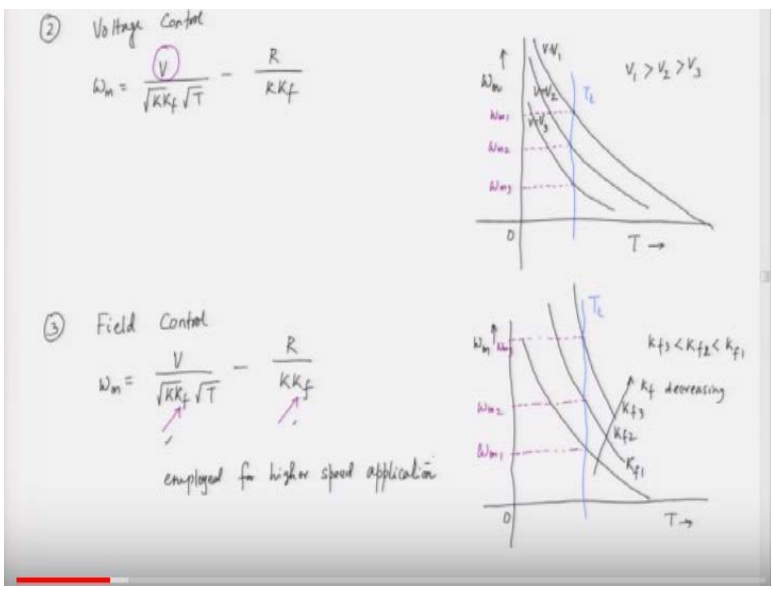

Now, let's delve into field control, which is an important method for adjusting the speed-torque characteristics of a motor. When we talk about field control, we are essentially changing the field constant, denoted as K_f. This constant appears in two terms of our equations.

If we plot the speed-torque characteristic with speed on the y-axis and torque on the x-axis, we can visualize this relationship. For instance, let's consider the speed-torque characteristic corresponding to a certain value of K_f, which we'll label as K_{f1}.

Now, as we decrease K_f, what happens? The no-load speed increases, and the negative torque component also rises. Consequently, the speed-torque characteristic shifts accordingly. For the next value, let's say K_{f2}, as we further reduce K_f, the no-load speed will continue to increase, and the negative torque will increase even more. We can denote this value as K_{f3}, where $K_{f3} < K_{f2} < K_{f1}$. So, as we decrease K_f, we see the speed-torque characteristic transforming in this manner.

Now, if we introduce a constant load torque into the scenario, the intersection of the load torque profile with the motor's speed-torque characteristic determines the operating point. For the first characteristic, we have a speed of ω_{m1}; for the second characteristic, the speed is ω_{m2}; and for the third characteristic, the speed is ω_{m3}. This shows that the speed increases with a reduction in the field constant K_f.

Thus, we can conclude that employing field control allows us to achieve higher speeds, making it particularly suitable for high-speed applications. We've explored the characteristics of both shunt (or separately excited) motors and series motors, and in the upcoming lectures, we will summarize the behaviors of these two types of motors in more detail.

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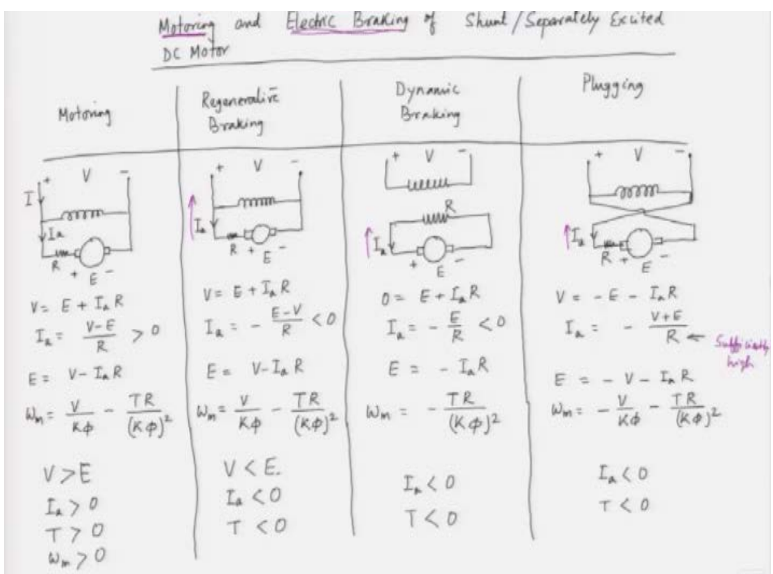

Now, let's begin our discussion on the motoring and electric braking of shunt or separately excited

DC motors. We have previously explored the motoring aspect, and now we will revisit it while focusing on various types of electric braking methods applicable to these motors. Our goal is to compare the motoring operation with the different braking techniques available.

To start, let's identify the various types of braking mechanisms we will cover alongside the motoring operation. We have regenerative braking, dynamic braking, and a method known as plugging. Each of these braking methods will be discussed in detail as we explore the motoring characteristics of DC motors.

Let's take a closer look at a DC motor. We have the field winding and the armature, which is connected to a voltage supply V. The armature carries a current denoted as I_a, while the armature resistance is represented by R, and the back electromotive force (EMF) is labeled as E.

In the motoring process, current enters the motor, resulting in the conversion of electrical energy into mechanical energy. We can write the equation for the armature circuit as follows:

$$V = E + I_a \cdot R.$$

From this equation, we can derive the armature current:

$$I_a = \frac{V - E}{R},$$

which is always positive during motoring. We can also express the back EMF as:

$$E = V - I_a \cdot R.$$

Furthermore, we have already established that the angular speed ω_m is given by:

$$\omega_m = \frac{V}{K\phi} - \frac{T_R}{K\phi^2}.$$

This equation represents the characteristics of a separately excited DC motor. It is important to note that for effective motoring operation, the applied voltage must be greater than the back EMF. Therefore, the condition for motoring is that the applied voltage V must exceed the back EMF E.

In this scenario, the armature current is positive, the torque is also positive, and naturally, the speed must be positive as well for proper motoring operation.

Now, let's delve into the concept of braking. What do we mean by the braking of a motor? Essentially, when we talk about braking, we refer to the process of reducing the speed of the motor. This means that the motor's speed is brought down to zero or, at the very least, reduced to a lower value. That is the essence of braking.

During braking, the motor can sometimes operate as a generator, delivering power back to the supply or to a resistive load. In the case of regenerative braking, the motor indeed functions as a generator, supplying power back to the DC source.

Let’s consider a circuit diagram for regenerative braking. We have the armature connected to an applied voltage V, with the field winding also included. The armature current is denoted as I_a, and we also have the armature resistance R and the back EMF represented as E.

We can apply Kirchhoff's voltage law in this scenario, which gives us the equation:

$$V = E + I_a R.$$

Now, rearranging this equation, we can express the armature current as:

$$I_a = -\frac{E + V}{R}.$$

Here, we see that this quantity is negative, indicating that for regenerative braking, the armature current is negative.

Next, we can derive the expression for the back EMF using the same equation as before, E = V - I_a R, which mirrors our approach in motoring. From this, we can find the expression for the angular speed ω_m:

$$\omega_m = \frac{V}{K\phi} - \frac{T_R}{K\phi^2}.$$

Notice that the equations for motoring and regenerative braking are structurally the same. However, the operating conditions differ significantly: for motoring, the armature current is positive, whereas in regenerative braking, the armature current is negative.

In this braking scenario, the applied voltage V is actually less than the back EMF E. This means that the current direction is reversed; it flows from the armature back into the circuit rather than from the supply into the armature. Thus, the current is being fed back into the system, indicating that the motor is effectively functioning as a generator during the braking process.

This indicates that the motor is functioning as a generator, supplying power back to the DC source. In this scenario, the torque is negative, while the speed can either be positive or negative. Thus, we have the following conditions: $V < E$, $I < 0$ (where the current I is negative), and $T < 0$. This confirms that the motor is indeed behaving as a generator.

Now, let's discuss dynamic braking. In this method, we continue to excite the field using a DC source, but the armature is disconnected from the power supply. Instead, the armature feeds current into a resistive load. In this setup, we have the armature current I_a flowing, and the back EMF is denoted as E.

We can establish an equation for this situation. Notably, there is no applied voltage because the circuit is effectively short-circuited at the applied voltage terminals. Thus, in the case of dynamic braking, the supply is removed from the armature, which is now connected solely to a resistance, denoted as R.

Using Kirchhoff's law, we can express this as:

$$0 = V_{\text{applied}} = E + I_a R.$$

From this equation, we can derive that:

$$I_a = -\frac{E}{R}.$$

As before, the current I_a is negative, which indicates that the current flows in the opposite direction, circulating through the resistance and dissipating energy as heat.

If we write the expression for the back EMF, we get:

$$E = -I R,$$

and since the applied voltage V = 0 for the armature, we can express the speed as:

$$\omega_m = -\frac{T_R}{K\phi^2}.$$

In this dynamic braking scenario, both the torque and the current are negative. The energy of the motor is therefore dissipated as heat within the resistive part of the armature.

Now, let's move on to the fourth method of braking, known as plugging. In plugging, we reverse the armature connections while keeping the field connections unchanged. This means we have an armature resistance R, and when we reverse the armature connections, we still maintain the field connection in its original configuration.

Now, we can analyze this setup using Kirchhoff's voltage law for the armature circuit. The voltage across the armature can be expressed as:

$$V = -E.$$

Considering the armature current I_a, we can express this as:

$$V = -E - I_a R.$$

From this equation, we find:

$$I_a = -\frac{V + E}{R}.$$

This method effectively allows the motor to rapidly decelerate by reversing the direction of current flow in the armature while the field remains steady, thereby enhancing the braking effect.

In plugging, it's crucial to understand that we reverse the armature voltage, which means that the armature resistance must be sufficiently high. This high resistance is necessary to limit the current flowing through the armature; otherwise, we risk experiencing an overcurrent condition.

Now, if we look at the equation for the back EMF, we have:

$$E = -V - I_a R.$$

From this, we can derive the equation for the motor speed:

$$\omega_m = -\frac{V}{K\phi} - \frac{T_R}{K\phi^2}.$$

This equation specifically pertains to the plugging operation. Here, it's important to note that the current must be negative; it flows in the opposite direction. As a result, we see that the applied voltage is essentially countered by the back EMF, leading to a situation where both the current and torque are negative.

These conditions are characteristic of the plugging method.

So far, we have explored several operational modes: motoring, regenerative braking, dynamic braking, and plugging. To fully appreciate the behavior of the machine, particularly in terms of its performance, we need to plot the speed-torque characteristics for all these different conditions—both during motoring and braking. This comprehensive analysis will help us better understand how the machine responds under various operational scenarios.

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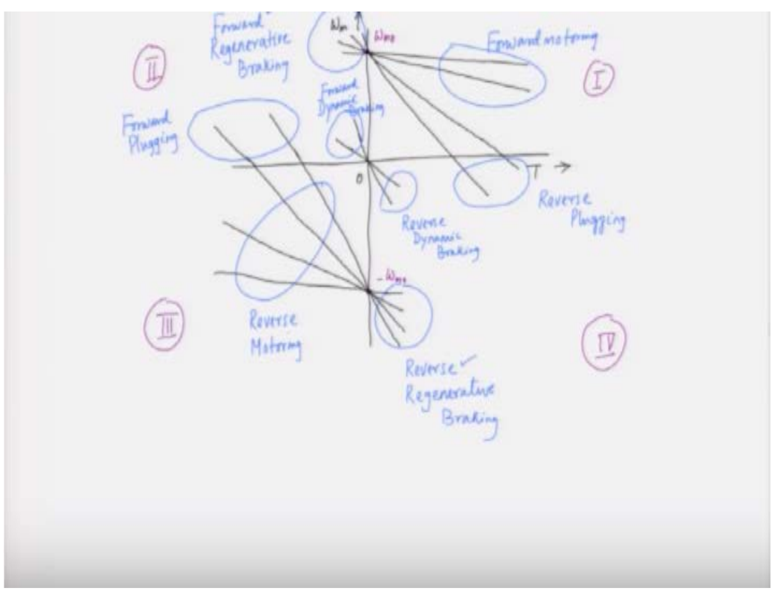

Now, let us delve into the speed-torque characteristic of a separately excited DC motor across all possible conditions. Here, we have the speed represented on the vertical axis and the torque on the horizontal axis. Typically, in the motoring mode, we observe this behavior, and as we increase the resistance, the characteristic curve changes accordingly. If we extend this analysis into the second quadrant, we see that the characteristic transitions in a specific manner.

In a similar vein, if we consider the scenario where we further increase the resistance, we obtain a new profile. When we engage in reverse motoring, the characteristic shifts again. If we continue to increase the resistance further, we arrive at what we might refer to as the no-load speed in the forward direction, denoted as ω_{m0}, while the no-load speed in the reverse direction is represented as $-\omega_{m0}$. This entire region pertains to what we call forward motoring, which resides in the first quadrant.

Now, the behavior represented in this segment corresponds to forward regenerative braking, which exists in the second quadrant. To clarify our quadrant designations: quadrant one encompasses forward motoring, while quadrant two focuses on the braking aspect. In this quadrant, we engage in forward regenerative braking, where energy is fed back into the supply, resulting in negative power in this context.

Moving on to the third quadrant, we observe that this segment represents reverse motoring, capturing all aspects of that operation. Furthermore, we also encounter reverse regenerative braking in this quadrant. Just as we have forward regenerative braking, we similarly define the reverse regenerative braking. Thus, when we refer to the negative direction, we classify it as reverse, whereas the forward motion is identified as forward braking or forward motoring.

This comprehensive understanding of the speed-torque characteristics across all quadrants enables us to effectively analyze the operational dynamics of the motor in various scenarios.

In the context of reverse speed, we refer to it as reverse motoring or reverse braking. Now, let's examine the specific part of the characteristic that appears here. If we revisit the equation, we realize that it pertains to the characteristics observed in the third and second quadrants, which correspond to the phenomenon known as plugging. When the no-load speed becomes negative, we accelerate into the second quadrant, leading to a condition we identify as plugging.

Within this framework, the section we are observing is classified as forward plugging, which lies in the second quadrant. Here, the speed is positive, thus we denote this behavior as forward plugging. Conversely, the part of the characteristic where the speed is negative is termed reverse plugging, which is located in the fourth quadrant. Again, in the fourth quadrant, we witness the braking behavior, specifically identified as reverse plugging.

Now, let’s discuss dynamic braking. In the case of dynamic braking, the applied voltage is set to zero. The speed-torque characteristic for this scenario is illustrated as follows: the no-load speed reaches zero at this point. This characteristic is primarily representative of dynamic braking, which we classify as forward dynamic braking and reverse dynamic braking, depending on the direction of operation.

When we analyze the speed-torque characteristic of a separately excited DC motor, we can clearly identify several operational modes: forward motoring, forward regenerative braking, reverse motoring, reverse regenerative braking, forward plugging, reverse plugging, as well as forward dynamic braking and reverse dynamic braking. This comprehensive characteristic effectively encapsulates the complete behavior of a separately excited DC motor.

Now, let us turn our attention to the characteristics of a series motor and explore its operational dynamics in a similar manner.

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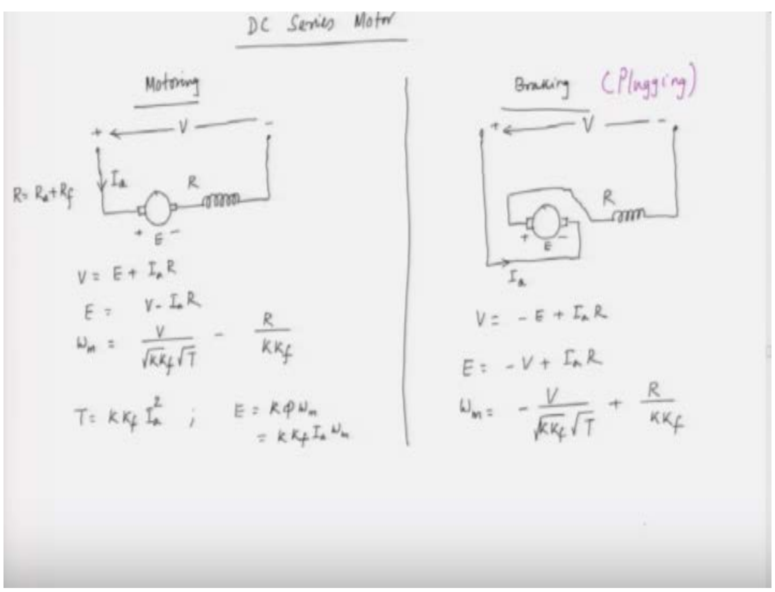

What we will be discussing now is the motoring operation of a series DC motor, as well as the braking mechanisms associated with this type of motor. To begin with motoring, we have already examined the circuit configuration for the series motor, where the field winding is connected in series with the armature. When we apply the DC voltage, we generate a back EMF, denoted as E. The total resistance of the circuit can be expressed as $R = R_a + R_f$, where R_a is the armature resistance and R_f is the field resistance. The current drawn by the motor is denoted as I_a.

In this scenario, we can formulate the equation as:

$$V = E + I_a R$$

Alternatively, we can express it as:

$$E = V - I_a R$$

The angular velocity, ω_m, can be defined by the equation:

$$\omega_m = \frac{V}{\sqrt{KK_f}} \sqrt{T - \frac{R}{KK_f}}$$

Here, the torque equation can be represented as:

$$T = KK_f I_a^2$$

This indicates that the torque is proportional to the square of the armature current. The back EMF can be expressed as:

$$E = K\phi\omega_m = KK_f I_a \omega_m$$

This encapsulates the motoring dynamics of a series DC motor.

Now, let's delve into the braking aspect. During braking, we modify the armature connections relative to the field winding. The applied voltage remains V, and we still have the back EMF E with the total resistance R. In this case, the voltage equation can be written as:

$$V = -E + I_a R$$

Alternatively, we can also represent it as:

$$E = -V + I_a R$$

For the speed, we can use the equation:

$$\omega_m = -\frac{V}{KK_f}\sqrt{T + \frac{R}{KK_f}}$$

This formulation corresponds to the braking operation. Specifically, this braking method is a special type known as plugging. In the context of series motors, when we discuss braking, we generally refer to plugging, which involves reversing the armature connection. This results in a decrease in motor torque, and notably, the torque becomes negative because of the reversed connection. Consequently, the torque can be expressed as:

$$T = -KK_f I_a^2$$

When the torque is negative, we categorize this operation as braking. Thus, we have an insightful understanding of both motoring and braking in series DC motors.

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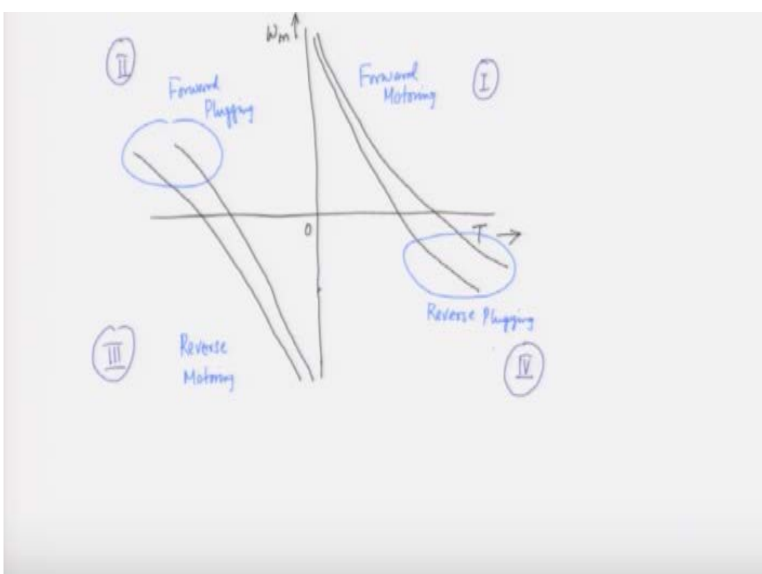

Now, let’s take a closer look at the speed-torque characteristic of a series motor. We plot the speed on the y-axis and torque on the x-axis. This is the framework for visualizing the speed-torque characteristics.

In this context, we can observe the characteristics for reverse motoring, as well. The portion representing forward motoring is clearly indicated, while the section corresponding to forward plugging is also present. Similarly, the area illustrating reverse motoring is identified, and the segment located in the fourth quadrant represents reverse plugging.

In a series motor, motoring occurs in both the first and third quadrants, while braking takes place in the second and fourth quadrants. It's important to note that one of the most popular methods of braking in a series motor is referred to as plugging. That concludes our discussion for today's lecture. So we stop here for todays lecture we will continue in the next lecture.