Fundamentals of Electric Drives

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Lecture – 39

Current Collector for Mainline Trains, Nature of Traction Load, Duty Cycle of Traction Drives

Nowadays, electric locomotives are nearly ubiquitous, primarily due to the extensive electrification of railway tracks. The majority of tracks have been electrified, which has led to the widespread use of electric locomotives. In these locomotives, power is supplied via an overhead line known as a catenary line. This system allows for efficient transmission of electricity, ensuring that trains can operate smoothly and reliably over long distances.

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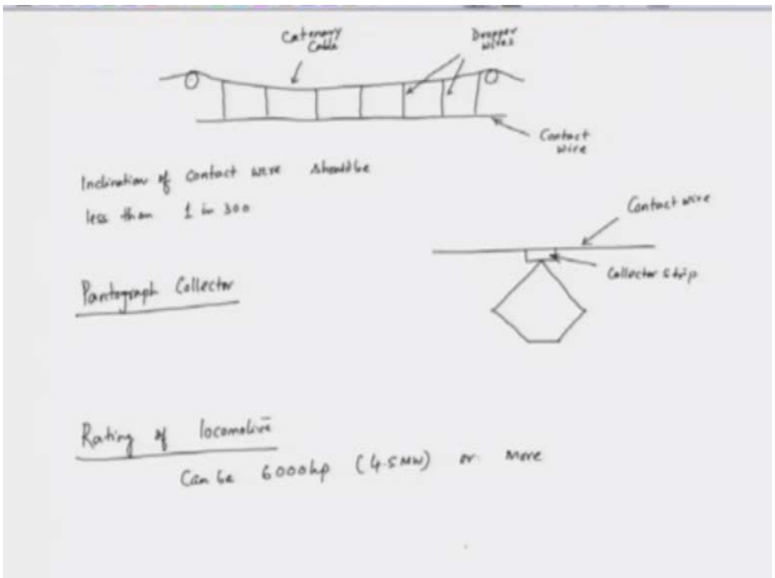

Let's discuss how power is supplied to electric locomotives. Above the train, we have catenary cables, which form the essential catenary line. Alongside this, there is a contact wire with which the locomotive establishes contact. This contact wire is maintained almost horizontally by what we call dropper wires. These dropper wires provide crucial support, ensuring that the contact wire remains nearly horizontal throughout its length.

The inclination of the contact wire must be less than 1 in 300, emphasizing the need for it to be as close to perfectly horizontal as possible. The catenary wire essentially serves as mechanical support, while the dropper wires are responsible for keeping the contact wire level.

To connect with the contact wire, the train employs a device known as a pantograph. The pantograph, or pantograph collector, resembles a pentagonal structure and plays a vital role in collecting electricity. It features a collector strip that interfaces with the contact wire, which itself is not fixed at a single point. Instead, it is staggered to ensure even contact with the collector strips as the train moves. This staggering helps distribute the wear on the contact strip and enhances efficiency.

When discussing the ratings of traction drives, we typically encounter figures as high as 6,000 horsepower, which translates to approximately 4.5 megawatts or more. This indicates we are dealing with high-power drives. Importantly, this power is not delivered by a single motor; rather, it is generated by a combination of motors, often four, six, or more, working in concert. These motors drive the axles, which are directly connected to the wheels of the train. Now, let's take a closer look at how these motors effectively drive the axles.

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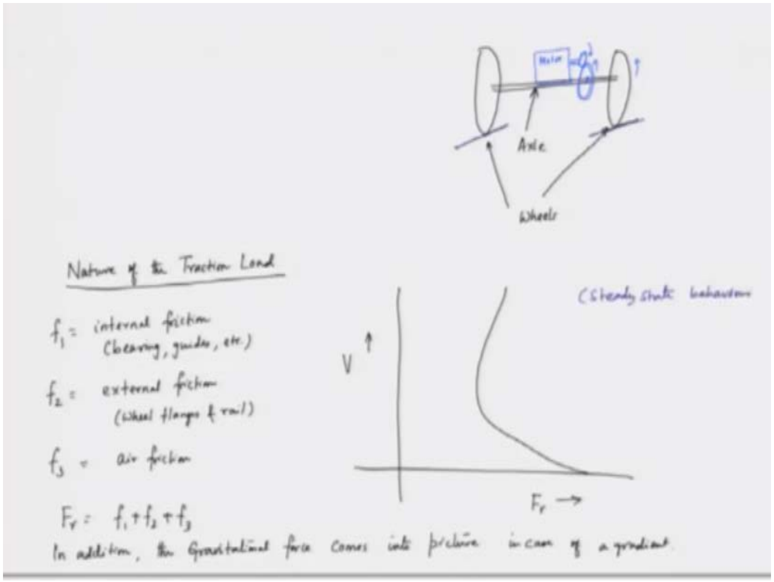

Let’s examine the components of the train's axles and wheels. Each axle is connected to two wheels, and these wheels operate on a predefined track. The motors are typically mounted on each axle; each axle houses one motor, allowing for efficient operation.

Now, regarding the gear arrangement, there’s a gear fixed to the motor and another gear connected to the axle. As the motor rotates, it drives the gear, which in turn causes the axle to rotate, leading to the movement of the wheels. This setup ensures a seamless transfer of power from the motor to the wheels, facilitating smooth motion along the tracks.

Now, let's shift our focus to the nature of the traction load. The traction load comprises various components, and its variation with speed can be represented graphically. On this graph, we plot speed against the traction load. This relationship is characterized by what we refer to as train resistance.

The train resistance can be broken down into several key components:

- F_1, which represents the internal friction, arising from elements such as bearing guides.
- F_2, termed external friction, occurs between the wheel flanges and the rail.
- F_3, representing air friction, comes into play as the train moves through the air at a certain velocity.

Thus, the total train resistance, denoted as F_r, is given by the equation:

$$F_r = F_1 + F_2 + F_3$$

As the train advances, it encounters these various forms of friction. Internal friction pertains to the interactions within the bearings and other mechanical components, while external friction is a result of the contact between the wheels and the track. Additionally, as the train speeds up, air friction becomes increasingly significant, as it directly opposes the train's forward motion. This comprehensive understanding of traction load is crucial for effective train operation and efficiency.

Air resistance plays a significant role in opposing the movement of the train, and we can identify three primary components contributing to this resistance: internal friction, external friction, and air friction. Additionally, we must consider gravitational forces that come into play, especially when the track has a gradient. When the track is perfectly horizontal, gravitational forces are negligible; however, in hilly terrains, the train may encounter both uphill and downhill gradients.

Depending on the slope of the track, gravitational forces will impact the train's movement. Thus, when dealing with inclined tracks, the gravitational force becomes an essential factor to account for.

Now, as we analyze the steady-state behavior of the train, an important parameter associated with traction arises. For the wheels to effectively run on the track, there must be a sufficient level of adhesion between the wheels and the rail. This adhesion is critical; without it, the train cannot move forward. When the motor rotates the wheels, it is this very adhesion that enables the train's forward motion.

While adhesion can be somewhat crudely likened to friction, in the context of electric traction, we specifically refer to it as adhesion. To quantify this interaction, we utilize a parameter known as the coefficient of adhesion. Let’s delve deeper into what the coefficient of adhesion entails.

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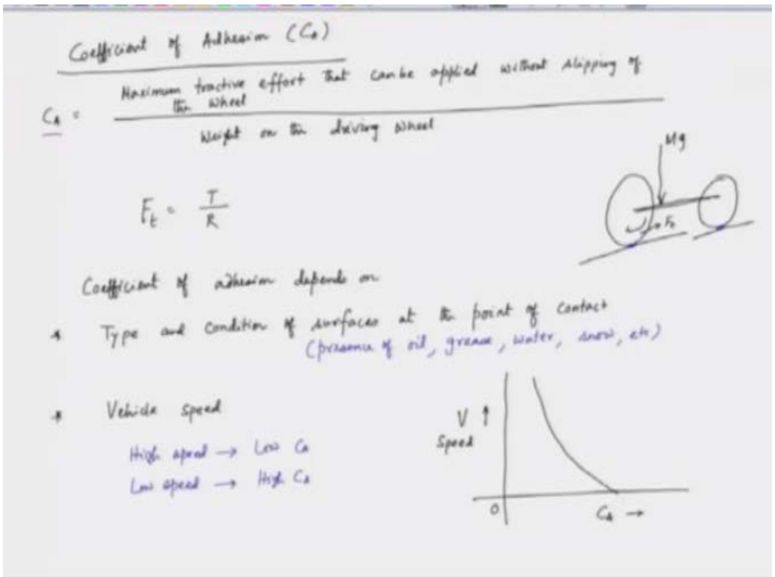

The coefficient of adhesion, often denoted as CA, is a critical parameter in understanding the traction of wheels on a track. So, what exactly does this coefficient represent? Simply put, the coefficient of adhesion is defined as the maximum tractive effort that can be applied without the wheels slipping, divided by the weight resting on the driving wheels.

Imagine a wheel resting on a track, which is connected to another wheel via an axle; both are also positioned on a track. There is a certain weight acting on this wheel, which can be expressed as $M \times g$, where M represents mass and g is the acceleration due to gravity. This weight is distributed between the two wheels.

As the wheel rotates, it must move forward, and that’s where the coefficient of adhesion comes into play. The maximum tractive effort that can be exerted without slipping of the wheel is fundamental to maintaining effective motion. This tractive effort, denoted as F_t, is generated by the motor, which produces torque. The relationship can be summarized as follows: the tractive effort F_t is equal to the torque generated by the motor divided by the radius of the wheel.

It is crucial that the tractive effort applied remains below a certain threshold. If the applied tractive effort exceeds this limit, the wheels may start to slip. When slipping occurs, it can lead to significant wear and tear on both the wheels and the track. The high-speed rotation of the wheel against the track will result in broadening of the track and deterioration of the wheel itself.

To prevent such damage and ensure the longevity of both the wheels and the track, it is essential to maintain the applied tractive effort below the permissible value. This careful management of tractive effort is vital for safe and efficient operation.

The coefficient of adhesion plays a crucial role in determining how effectively a wheel can grip the track. This coefficient is influenced by several key factors. Firstly, it depends on the type and condition of the surfaces at the point of contact. When we talk about contact, we must consider the characteristics of both the track and the wheel.

For instance, the presence of substances such as oil or grease on the track can significantly reduce the coefficient of adhesion. Similarly, water can create a slippery surface, further diminishing the coefficient of adhesion. On a rainy day, when the track is wet, we can expect a decrease in this crucial coefficient. Additionally, if snow is present on the track, it will also adversely affect the coefficient of adhesion.

In essence, the condition of the track, whether it is clean, oily, or wet, directly impacts the adhesion between the wheel and the track. Furthermore, the coefficient of adhesion is also affected by the speed of the vehicle. Interestingly, when the vehicle speed is high, the coefficient of adhesion tends to be lower. Conversely, at lower speeds, the coefficient of adhesion increases.

If we were to graph the relationship between vehicle speed, denoted as V, and the coefficient of adhesion, we would observe a downward trend. This indicates that as speed increases, the coefficient of adhesion decreases, and at lower speeds, we find a relatively higher coefficient of adhesion. Thus, high speed corresponds to low adhesion, while low speed indicates a higher coefficient of adhesion. This understanding is vital for ensuring safe and efficient operation in varying conditions.

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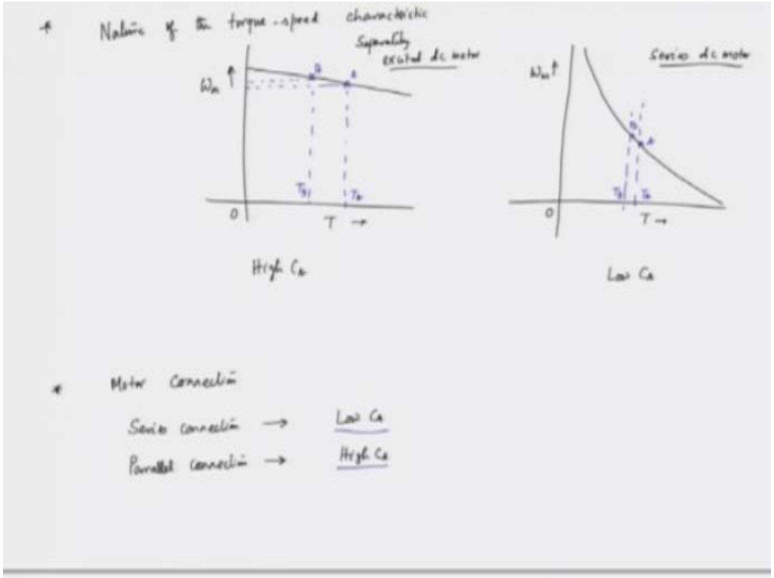

When the vehicle speed is low, the coefficient of adhesion is high, illustrating a direct relationship between these two factors. However, the coefficient of adhesion also depends on other parameters, such as the nature of the torque-speed characteristic of the motor being used.

Let’s consider two types of motors: the first is a separately excited DC motor, which has a relatively stable speed-torque characteristic. In this case, when the wheel begins to slip, the torque decreases quite rapidly. This rapid reduction in torque allows the wheel to regain its grip on the track, resulting in a higher coefficient of adhesion.

To visualize this, imagine the motor operating at a certain point on the torque-speed curve. If a wheel slip occurs, the speed might increase from point A to point B. During this transition, the torque would drop significantly from T_A to T_B. As the torque decreases, the tractive effort also diminishes, enabling the wheel to re-establish contact with the track and preventing further slippage. Thus, this scenario yields a higher coefficient of adhesion.

In contrast, let’s examine a series DC motor. When wheel slippage occurs in this case, the speed also increases, say from point A to point B. However, the reduction in torque is not as pronounced compared to that of the separately excited DC motor. This relatively smaller change in torque means that the wheel may not regain its grip as effectively, resulting in a lower coefficient of adhesion.

Thus, the interaction between motor type and the resulting torque-speed characteristics plays a crucial role in determining the coefficient of adhesion, particularly during instances of wheel slippage. Understanding these dynamics is vital for optimizing traction and performance in various driving conditions.

In the case of a series motor, the coefficient of adhesion (CA) tends to be lower. This is significant because while the separately excited DC motor achieves a higher coefficient of adhesion, a series DC motor results in diminished adhesion. Another crucial factor influencing the coefficient of adhesion is the motor connection configuration.

When motors are connected in series, a wheel slip leads to an increase in back electromotive force (EMF), causing the current across all motors to decrease. As a result, even motors connected to wheels that are not slipping will experience reduced torque. This interconnectedness in a series setup means that the overall performance is negatively affected, resulting in a lower coefficient of adhesion.

On the other hand, in a parallel motor connection, only the motor associated with the slipping wheel will experience a reduction in torque. This allows the remaining motors to maintain their torque output, leading to a relatively higher tractive effort and, consequently, a higher coefficient of adhesion.

Now, let’s shift our focus to the duty cycle of the traction drive. We will examine how the traction drive, or locomotive, behaves as it moves from one station to another, particularly in terms of changes in speed and torque. Understanding these dynamics is essential for optimizing the efficiency and performance of the traction drive during operation.

Let’s delve into the duty cycle of a traction drive. Consider a locomotive journeying from one station to another. It begins with an acceleration phase, reaches its maximum speed, and then, as it approaches the next station, it must brake to come to a complete stop. The typical speed variation throughout this process can be illustrated as follows, with speed plotted against time.

Initially, the speed remains constant, and then we observe a linear increase as the locomotive accelerates from a standstill. On the x-axis, we have time, while the y-axis represents speed.

During this journey, we experience distinct phases: constant torque, constant power, a free-running period, a coasting period, and finally, a braking period.

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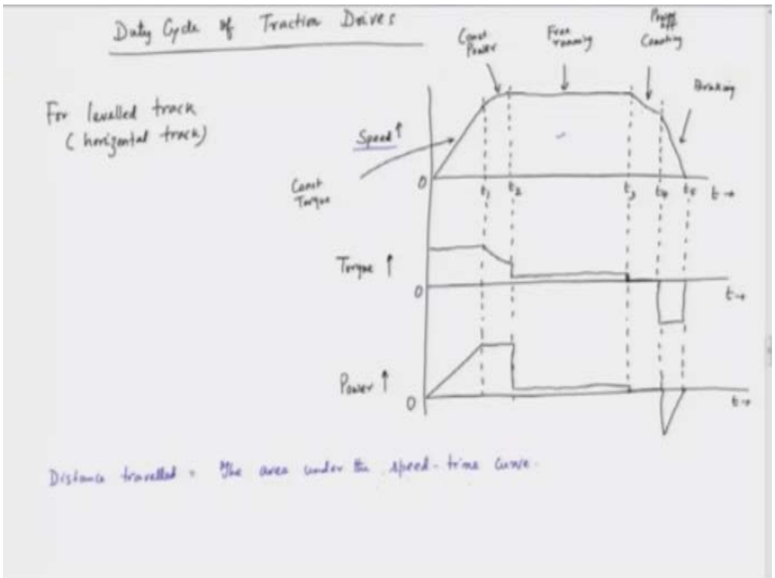

The speed profile resembles a trapezoid. In the first segment, where the speed is nearly constant, we refer to this phase as the constant torque region, extending from time 0 to t_1. Following this, from t_1 to t_2, the power remains constant, which we identify as the constant power region. At this point, the speed reaches its maximum value, and the locomotive continues to run freely during the free-running period.

As we transition into the next phase, we encounter the coasting period, where the motor is switched off, and power is no longer applied. This segment is also known as the power-off period. Finally, we have the braking period, which takes place from t_4 to t_5, marking the locomotive's transition from free movement to a complete stop.

So, the duty cycle of the traction drive can be broken down into the following intervals: from 0 to t_1 is constant torque, t_1 to t_2 is constant power, t_2 to t_3 is the free-running period, t_3 to t_4 is the coasting period, and t_4 to t_5 is the braking period. Each of these phases plays a crucial role in the overall performance and efficiency of the locomotive during its journey.

Let's take a closer look at how torque varies throughout the locomotive's operation. From time 0 to t_1, the torque remains nearly constant at its maximum value. This initial phase is crucial as it provides the necessary force for acceleration. Then, from t_1 to t_2, we observe a decrease in torque, even though the power stays constant. During this period, the locomotive reaches its maximum possible speed, at which point only the frictional torque and minimal air resistance are applied.

Moving forward to the interval from t_3 to t_4, the motor is switched off, resulting in zero torque. Finally, during the braking phase, from t_4 to t_5, we apply a negative torque to facilitate braking. Therefore, the torque profile throughout the operation exhibits these defined changes.

Now, let's examine how power varies with respect to time. Initially, as the motors are powered on, the power gradually increases until it reaches the maximum rated power. The locomotive then operates at this maximum power. However, during the free-running period, power begins to decline, eventually dropping to zero when the motor is switched off. As we enter the braking phase, the torque becomes negative, which consequently causes the power to also turn negative. This is because power is being fed back to the supply during braking. As the speed decreases and ultimately approaches zero, the power also returns to zero.

These variations in speed, torque, and power are crucial for understanding the locomotive's performance. However, it is essential to note that these plots assume there is no gravitational force at play; they represent conditions on a level track. When we say the track is leveled, it means that it is absolutely horizontal, without any gradients.

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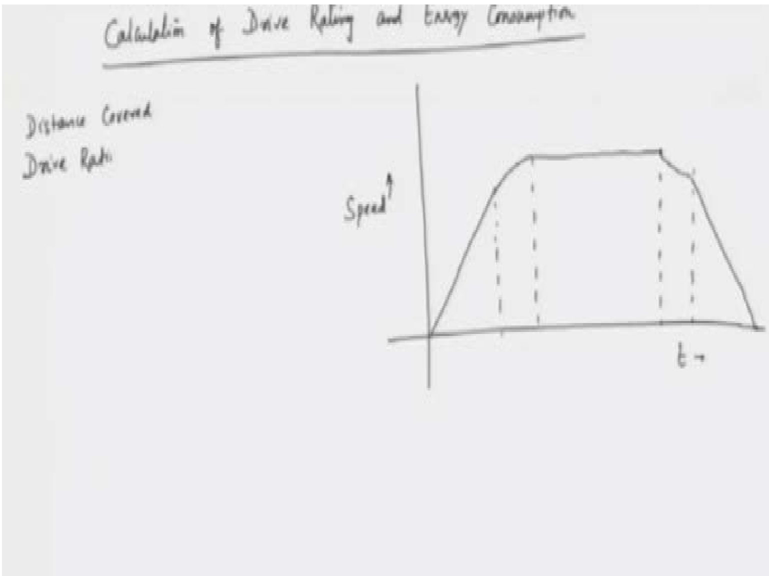

To determine the distance covered by the locomotive, we must look at the area under the speed-time curve. This area essentially represents the distance traveled. Therefore, to find the distance, we calculate the area under this speed-time curve, which gives us the total distance that the train has traveled during its journey.

Now, let’s discuss the calculations related to drive rating and energy consumption. We will begin by revisiting our speed versus time diagram. On the y-axis, we have speed plotted, which includes distinct periods such as constant torque, constant power, free-running, coasting, and braking. Each of these periods plays a crucial role in the overall dynamics of the locomotive's journey.

Our first task will be to determine the distance covered during these phases. Additionally, we will calculate the drive rating, which is essential for understanding the locomotive's performance. As we explore how a train transitions from one station to another, we’ll analyze the different modes it experiences, constant torque, constant power, free-running, coasting, and braking.

The subsequent calculations for distance covered and drive rating will be addressed in our next lecture, where we will break down the necessary steps and formulas to complete these evaluations accurately.