Efficiency Challenge Electric Vehicle

Differential in Electric Vehicles

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Comprises general and technical information regarding the electronic differential in Electromobile and Hydromobile vehicles. This document is shared for illustrative and cooperative purposes.

1 INTRODUCTION

The increasing usage of renewable energy sources with a new global perspective has begun shaping our future accordingly. Due to efforts against global warming, technology has been developing continuously in this direction and energy consumption values have started to decrease with each passing day. One of the most significant examples of this development is electric vehicles. Although they are not commonly used today, they are becoming more and more popular; new studies and innovative projects are being carried out continuously in this field as it is believed that 100% of the population will be using electric vehicles in the future. Some of the most important advantages of electric vehicles are that they have “zero” carbon release and are cost-effective in terms of fuel costs in comparison with internal combustion engine vehicles. However, there are several limitations regarding these vehicles. New solutions are being thought of each day regarding these limitations. There are several aspects of these vehicles that still need to be improved, one of which is the electronic differential issue.

Traditional vehicles comprise a large engine and a differential mechanism that transfers the power it receives from the engine to the wheels. This mechanism can operate without any problems, but it is disadvantageous in that it occupies a large space and the mechanism is heavy. As internal combustion engines are used in traditional vehicles, an alternative to the mechanical differential was not sought previously. However, as electric motors used in electric vehicles are available in several types and sizes, and as they can be better controlled in comparison with internal combustion engines, flexibility is possible. This flexibility allows us to mount the electric motors directly onto the driving system (hub motor for the wheels) of the vehicle without the requirement for even a power transmission. By this means, the vehicle is free of a large mounted metal mass and the vehicle is significantly lighter. This advantage also enables reduction of loss of energy. However, these motors that have been directly mounted onto the driving system of the vehicle need to carry out the function usually carried out by the differential mechanism located in traditional vehicles.

1.1 Historical development of the differential mechanism

The carriage, one of the first primitive vehicles in history, actually forms the basis for the development of the differential mechanism. It was originally very difficult to make turns with carriages. Later on, it was thought that the front wheels needed to turn in order for the carriages to make easier turning manoeuvres. In Figure 1.1, the turning of the front wheels as a whole can be seen during manoeuvring around a road curve.

Figure 1.1 The carriage manoeuvring around a curve

Following this development, internal combustion vehicles with chassis, shaft, and axle mechanisms were developed. The problem in such vehicles was that they needed a separate steering control system as the drive system was located inside the vehicle. However, another problem was also created. While going around a curve, the inner and outer wheels were forced to turn at different speeds. As it can be observed in Figure 1.2, the distance that the outer wheel needs to travel is longer than the distance that the inner wheel needs to travel.

Figure 1.2 Covered distance of inner and outer wheels at the curve

This problem was previously solved by connecting the drive system to only one of the wheels in vehicles. Namely, in a 4-wheel vehicle, the motor only provided driving motion to one wheel. This, of course, was not a stable system. Following this, a modern differential mechanism was developed that solved the above-mentioned problems.

1.2 Modern Differential Mechanism

The modern differential system has been developed as a mechanism that comprises several gear systems inside it. It also has a power transmission element that provides balanced turning.

The differential mechanism is basically a power transmission tool located between the shaft and the axle. The location of the differential in a vehicle driven by the rear 2 wheels in a rear wheel drive vehicle can be seen in Figure 1.3.

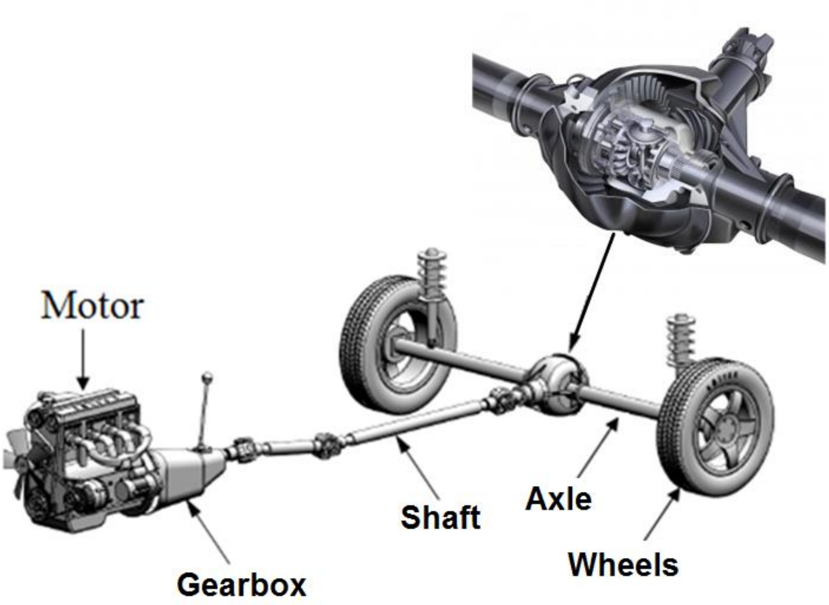

Figure 1.3 Vehicle transmission components

The functions of the differential mechanism can be listed as follows:

- Reduce the speed of the motion received from the shaft and increase torque.
- Ensure that the inner wheel turns slowly and the outer wheel turns faster during turns, thereby ensuring easy turning around corners or curves, without wheel slipping and excessive vehicle yaw.

The most important duty of the differential for us is its function when the vehicle is manoeuvring a curve. When a vehicle is manoeuvring a curve, the inner wheels should turn slowly and the outer wheels should turn quickly. In the event of a corner, the force transmitted to the road by means of the gear mechanisms inside the differential is adjusted according to the inner wheel, which is forced to turn more slowly. The outer wheel speed is increased in order to acquire torque balance inside the differential. In this way, stability in turning manoeuvres is ensured.

1.3 Differential Mechanism in Electric Vehicles

Although it is not correct to make comparisons as the electric vehicles of today are still largely conceptual, various applications exist. There are electric vehicles that comprise a differential mechanism inside the standard transmission means and a single large electric motor similar to traditional systems; there are also electric vehicles that do not have transmission means but have 4 different electric motors on all 4 wheels. However, as was mentioned before, it is obvious that it would be advantageous to use 2 or 4 motors that are smaller in size. A block diagram for two vehicles having 2 motors can be seen in Figure 1.4.

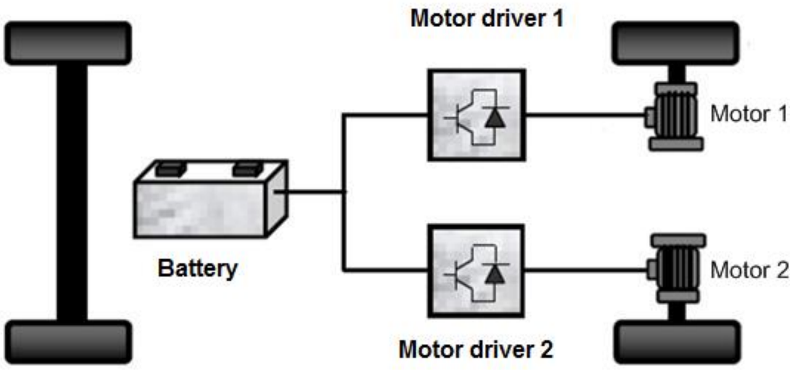

Figure 1.4 Electronic Differential

In electric vehicles where a plurality of electric motors (2 or 4) is used, as a mechanical differential mechanism is not present, it is necessary that this procedure be carried out by controlling the motors electronically.

1.4 Electronic Differential

First of all, the conditions and limitations need to be defined in order to understand the electronic differential control system. In order to achieve this, the conditions in which the differential system operates mechanically and how it operates need to be examined in detail. One of the most important conditions is the following:

- The mechanical system is a moment control-based system wherein a torque balance is established during turning that results in stable manoeuvres with lower angular speeds of inner wheels and higher angular speeds of outer wheels.

A similar approach may be taken regarding the mechanical differential during electronic differential applications. As a matter of fact, this is the first method that comes to mind. In this method the torques of the wheels are measured and they can be adjusted such that an inversely proportional power distribution is achieved, similar to the mechanical system, and the speed can be adjusted such that balanced cornering can be provided.

An advanced electronic differential unit must be capable of the following:

- ***Must manage the difference of speed of the turning wheels suitably during cornering,***
- ***Must not deviate from the road when it is desired for the vehicle to move straight,***
- ***Both wheels need to be able to maintain the direction when going straight under different road conditions and speed differences (slip) between the wheels need to be tolerated,***
- ***Moving in a straight line needs to be possible when the vehicle is travelling on rough roads.***

It can be presumed that proper control is provided as long as these four conditions are met.

2 EXAMINATION OF THE CORNERING DYNAMICS OF VEHICLES

2.1 Cornering Kinematics

In Figure 2.1, a 4-wheel vehicle turning left with the provided cornering parameters can be observed. If it is presumed that the vehicle turns left at a very slow speed, it can also be presumed that the vehicle is not sliding and the kinematics during turning between the inner and outer wheels can be explained. This geometry is also known as *Ackerman geometry* and is defined as follows:

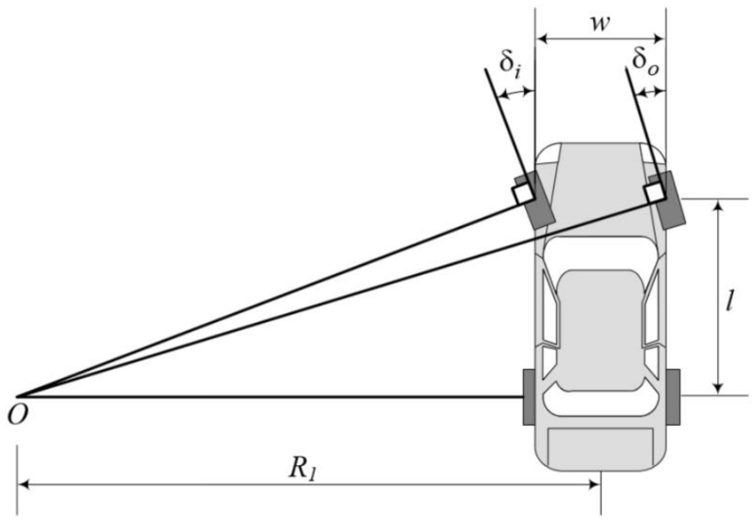

Figure 2.1 The Ackerman geometry parameters of a vehicle performing turning via the front wheels.

The length of the axle or the driving track that carries the rotatable wheels is shown by “w”. The distance between the front and the rear axle, or namely the axle distance, is shown by “l”. The vehicle track and the axle distance are the main parameters that show the characteristics of the vehicle during kinematic examination. These parameters can be thought of as vehicle width and length for kinematic analysis.

The connection between the inner wheel turning angle δ_i and the outer wheel turning angle δ_o, where the rotating centre of the vehicle going around a corner is *O*, can be defined as follows according to Figure 2.2.

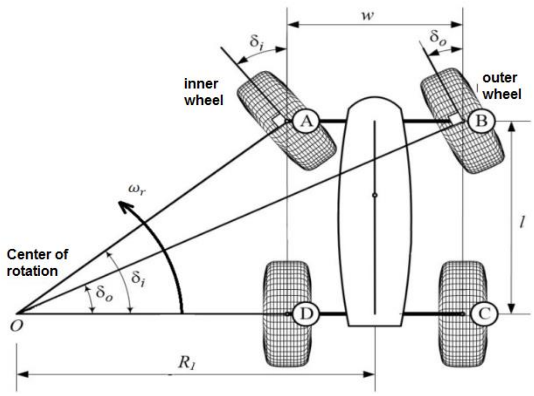

Figure 2.2 Analysis of the rotation angles of the inner and outer wheels

If the *OAD* and *OBC* triangles in the figure are used, the equations below are obtained.

$$\tan\delta_i = \frac{l}{R_1 - \frac{w}{2}} \qquad [1]$$

$$\tan\delta_o = \frac{l}{R_1 + \frac{w}{2}} \qquad [2]$$

If R_1 is obtained from these equations:

$$R_1 = \frac{w}{2} + \frac{l}{\tan\delta_i} \qquad [3]$$

$$R_1 = -\frac{w}{2} + \frac{l}{\tan\delta_o} \qquad [4]$$

The relation between δ_i and δ_o can be calculated from the above two equations:

$$\delta_o = \tan^{-1}\left(\frac{l}{w + \frac{l}{\tan \delta_i}}\right) \qquad [5]$$

As the definition of the turning angle differences between the inner and outer wheel is calculated by Ackerman geometry, now the angular speed difference between the vehicles during turning needs to be found. In order to achieve this, the parameters in Figure 2.2 can be given as follows:

ω_r is defined as the angular speed according to the rotation centre of the vehicle. If the length of *OA* according to the *OAD* triangle shown in the figure is defined as R_i and the *OB* length can be defined as R_o on the *OBC* triangle, the speed difference between the rotating wheels of the vehicle will be proportional with said radii. Moreover, ω_i and ω_o are defined as the angular speed of the inner and outer wheels of a vehicle and R_w is defined as the radius of the pneumatic wheel. If definitions are written according to these parameters, the following equations will be obtained:

$$\omega_i \times R_w = \omega_r \times R_i \qquad [6]$$

$$\omega_o \times R_w = \omega_r \times R_o \qquad [7]$$

If R_i and R_o are replaced by the expressions obtained from the *OAD* and *OBC* triangles:

$$R_i = \frac{l}{\sin \delta_i} \qquad [8]$$

$$R_o = \frac{l}{\sin \delta_o} \qquad [9]$$

If R_i and R_o are written in their places in equation [6], the following equation is obtained:

$$\frac{\omega_i}{\omega_o} = \frac{\sin \delta_o}{\sin \delta_i} \qquad [10]$$

According to this equation, the drive wheels will rotate at the same angular speed when a vehicle with a rear wheel drive with front wheel direction control is going straight and the angle of the direction wheels will be “0”. When the vehicle is going around a curve, the inner wheel needs to slow down and the outer wheel needs to speed up. As the motors of the rear wheel where the drive system of the vehicle is located form the base of the rotation angle, and if it is taken into account that the centre of gravity of the vehicle is located in the middle of these two drive wheels, it can be concluded that the angular speed differences between the inner and outer wheels will be equal to each other.

If we presume that both wheels rotate at the angular speed of ω on a straight road, the angular speed of the outer wheel needs to be calculated as $\omega_o = \omega + x$ and the angular speed of the inner wheel needs to be calculated as$\omega_i = \omega - x$.

$$\frac{\omega + x}{\omega - x} = \frac{\sin \delta_i}{\sin \delta_o} \qquad [11]$$

If the definition is updated again according to this approach, the equation above can be obtained.

If x is calculated from this equation, the mathematical statement of the difference in the angular speed of the inner and the outer wheels as soon as the vehicle is manoeuvring a corner can also be obtained.

$$x = \omega \times \left(\frac{\sin \delta_i - \sin \delta_0}{\sin \delta_i + \sin \delta_0}\right) \qquad [12]$$

2.2 REFERENCES

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