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Analysis of Acceleration Performance Improvement for Electric Vehicle Using 2-Speed Transmission

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2단변속기를 사용한 전기차의 가속성능 향상 분석

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ABSTRACT

In this study, the acceleration performance improvement was analyzed for a 2-speed transmission applied EV. An EV simulator was developed to analyze the EV acceleration performance. The EV simulator includes a load transfer model between the front and rear. Thus, the EV simulator can analyze the acceleration performance difference between the front-and rear-wheel drive EVs. From the simulation results, it is deduced that the acceleration performance can be improved by 7.96% for the front-wheel drive EV and 16.10% for the rear-wheel drive EV. The 2-speed transmission can improve the acceleration performance without decreasing its maximum velocity. Moreover, the 2-speed transmission can improve the acceleration performance of the rear wheel drive more than that of the front-wheel drive EV.

Keywords : Electric Vehicle(전기자동차), Transmission(변속기), Two Speed(2단), Powertrain(파워트레인) Acceleration Performance(가속성능)

1. Introduction

An electric vehicle (EV) uses an electric motor for propulsion. The constant power range of an electric motor is dependent on its base rotational speed. In addition, most EVs use single gear ratios instead of multi-gear ratios[1]. Moreover, the constant torque range of an electric motor is dependent on its base rotational speed. If the electric motor is operated in the constant torque range, the transmission can improve the acceleration performance of the EV; the constant torque range is narrower than the constant power range. Thus, most EVs use the -speed transmission to ensure better acceleration performance[2]. In contrast, conventional internal combustion engines do not have a constant power range and use a transmission with multi-gear ratios[3].

Furthermore, internal combustion engine vehicles often use four-speed transmission[4 6]. To design an

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EV powertrain, it is essential to determine the specifications of the motor and battery[7] and whether a transmission is required. Therefore, the usage of two-speed transmission in an EV is determined by analyzing the acceleration improvement of the EV owing to the application of the two-speed transmission. Thus, in this study, acceleration performance improvement of an EV owing to the application of two-speed transmission is analyzed. Furthermore, an EV simulator was developed to analyze the EV acceleration performance.

2. EV Simulator

In this study, the EV simulator was developed based on a previous study[3]. The specifications of the EV are presented in table 1. Additionally, the weight transfer was considered in the simulation. Fig. 1 shows the weight transfer on the vehicle. The front and rear weights are expressed as follows:

$$W_f = \frac{L_r}{L_f + L_r} Mg \tag{1}$$

$$W_r = \frac{L_f}{L_f + L_r} Mg \tag{2}$$

In the above equations, L_f is the length between the front wheel and the center of mass L_r is the length between the rear wheel and the center of mass, M is the vehicle mass, and g is the acceleration of gravity. Considering the inertial force (Ma) in Fig. 1, the front and rear normal forcescan be expressed as follows:

$$N_f = W_f - \frac{h}{L_f + L_r} Ma \tag{3}$$

$$N_r = W_r + \frac{h}{L_f + L_r} Ma \tag{4}$$

where N_f is the front normal force, h is the height

Table 1 Vehicle specifications

Motor Max. Power	80kW
Motor Max, Torque	280Nm
Motor base RPM	2,730RPM
Motor Max. RPM	10,390RPM
Mass	1,525kg
Cd	0.29
Frontal Area	2.27m^2
Tire rolling resistance coefficient	0.009
Tire radius	0.316m
Tire friction coefficient	1
Length between the front wheel and the center of mass	1.4m
Length between the rear wheel and the center of mass	1.4m
Height between the vehicle bottom and the center of mass	0.6m

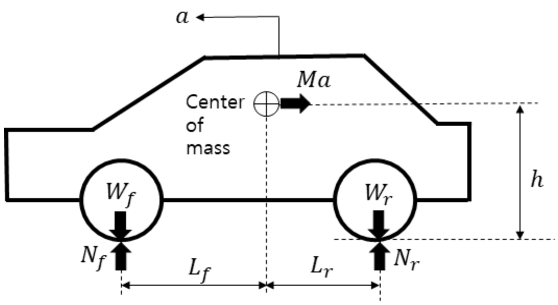

Fig. 1 Vehicle weight transfer

represents the length the vehicle bottom and the center of mass, and N_r is the rear normal force. From equations (3) and (4), the maximum traction forces can be calculated as follows:

$$F_{f\_\max} = \mu N_f \tag{5}$$

$$F_{r\_\max} = \mu N_r \tag{6}$$

where $F_{f\_\max}$ is the maximum traction force of the front wheel, μ is the tire friction coefficient and $F_{r\_\max}$ is the maximum traction force of rear wheel. From equations (3) and (4), it can be inferred that the rear normal force is bigger than the front normal force during acceleration. Thus, from equations (5) and (6), it can be inferred that the rear wheel can produce a larger traction force than the front wheel during acceleration. The tire friction coefficient changes owing to road conditions, such as dry, rainy, snowy, and icy. However, in this study, the road condition was assumed to be dry. Thus, the tire friction coefficient was one (1.0)[8].

3. EV Simulation

In this study, the acceleration performance improvement of the EV owing to the two-speed transmission was evaluated. The 0-100 km/h time of the single-gear-ratio EV and two-speed-gear-ratio EV was compared. To compare the 0-100 km/h time, the optimal gear ratios of the two vehicles were determined because the best 0-100 km/h time is observed when optimal gear ratios are used. To determine the optimal gear ratios, iterative simulations were performed. Fig. 2 shows the iterative simulations. In this study, the iteration step is one . The acceleration performance simulations were performed for all combinations of the first and second gear ratios. From equations (5) and (6), it can be inferred that the acceleration performances of the front-wheel-drive EV and rear-wheel-drive EV can be different. Thus, in this study, the acceleration simulations were performed for both the front- and rear-wheel-drive EVs.

3.1 Front wheel drive EV

Table 2 shows the simulation results of the 0–100 km/h time for the front-wheel-drive EV. The iterative simulations are performed for the gear ratios from 1 to 8. It is because the 0-100 km/h time does not change after the gear ratio 8. If the gear ratio is bigger than 8, the driving force is bigger than equation (5). Therefore, the tire is unable to provide the driving force. Thus, the 0-100 km/h time remains the same.

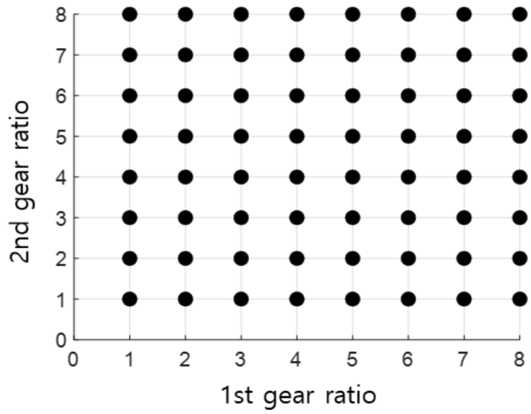

Fig. 2 Iterative simulations

Table 2 Simulation results of 0-100 km/h time for the front wheel drive EV

0-100 km/h time of front wheel drive EV, [sec]								
1st gear \ 2nd gear	1	2	3	4	5	6	7	8
1	70.78	29.13	18.39	13.78	11.75	10.68	10.04	9.84
2	29.13	29.13	18.39	13.78	11.75	10.68	10.04	9.84
3	18.39	18.39	18.39	13.78	11.75	10.68	10.04	9.84
4	13.78	13.78	13.78	13.78	11.74	10.67	10.04	9.83
5	11.75	11.75	11.75	11.74	11.75	10.67	10.03	9.83
6	10.68	10.68	10.68	10.67	10.67	10.68	10.04	9.83
7	10.04	10.04	10.04	10.04	10.03	10.04	10.04	9.83
8	9.84	9.84	9.84	9.83	9.83	9.83	9.83	9.84

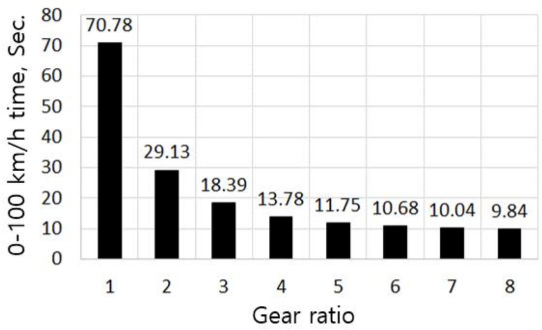

Fig. 3 Simulation results of the 0-100 km/h time for the single gear ratio front wheel drive EV

Table 3 Simulation results of maximum velocity for the front wheel drive EV

Maximum velocity of front wheel drive EV, [km/h]								
2nd gear / 1st gear	1	2	3	4	5	6	7	8
1	123	197	200	201	201	199	172	154
2	197	197	200	201	201	201	201	201
3	200	200	200	201	201	201	201	201
4	201	201	201	201	201	201	201	201
5	201	201	201	201	201	201	201	201
6	199	201	201	201	201	199	199	199
7	172	201	201	201	201	199	172	172
8	154	201	201	201	201	199	172	151

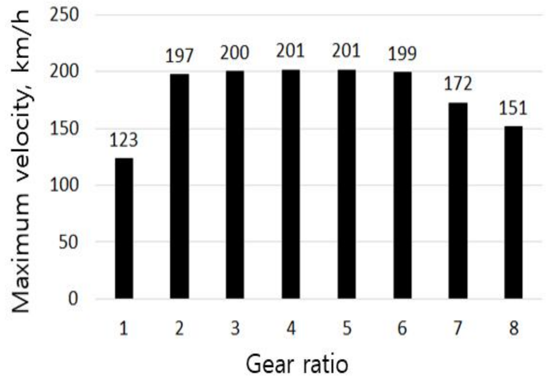

Fig. 4 Simulation results of the maximum velocity for the single gear ratio front wheel drive EV

As shown in table 2, when the first gear ratio was 3, and the second gear ratio was 8, the 0-100 km/h time was 9.84 sec. In addition, when the first gear ratio was 8, and the second gear ratio was 3, the 0-100 km/h time was the same as that of the aforementioned case. This can be attributed to the fact that the iterative simulations were performed based on the square matrix, such as Fig. 2. Therefore, table 2 exhibited diagonal symmetry. A first and second gear ratio of 5 implies that the single-gear ratio EV had a gear ratio of 5. Thus, the diagonal line in table 2 represents the 0-100 km/h time of the single-gear-ratio front-wheel-drive EV. Fig. 3 shows the simulation results of the 0-100 km/h time for the single-gear-ratio front-wheel-drive EV. A better 0-100 km/h time was observed at a higher gear ratio. Therefore, the maximum velocity should be considered. Table 3 shows the simulation results of the maximum velocity for the front-wheel-drive EV. The diagonal line of table 3 represents the maximum velocity of the single-gear-ratio front-wheel-drive EV. Fig. 4 shows the simulation results of maximum velocity for the single-gear-ratio front-wheel-drive EV. When the single gear ratio was 1, the maximum velocity was 123 km/h. However, for a single gear ratio of 2, the maximum velocity was 197 km/h. This can be attributed to the fact that a larger gear ratio provides sufficient driving force to overcome the air drag force of the vehicle. When the single gear ratio was 7, the maximum velocity decreased because the higher gear ratio accelerated the motor speed. Thus, the motor speed reached a maximum value, and the vehicle attained its maximum velocity.

Table 4 shows the optimal gear ratio of the single-gear-ratio front-wheel-drive EV. When the EV had a maximum velocity of over 170 km/h, the optimal gear ratio was 7, and the 0-100 km/h time was 10.04 seconds. In addition, when the EV had a maximum velocity of over 170 km/h, the optimal gear ratio was 6, and the 0-100 km/h time was 10.68 s.

Table 5 shows the optimal gear ratio of the two-speed-gear-ratio front-wheel-drive EV. When the EV had a maximum velocity of over 170 km/h, the optimal two-speed gear ratio was 7 8, and the 0-100 km/h time was 9.83 seconds, which is 0.21 seconds faster than the 0-100 km/h time for the single-gear-ratio front-wheel-drive EV; this implies that the acceleration performance was improved by

2.09%. When the EV had a maximum velocity of over 170 km/h, the optimal two-speed gear ratio was 6 & 8, and the 0-100 km/h time was 9.83 seconds, which is 0.85 seconds faster than the 0-100 km/h time for the single-gear-ratio front-wheel-drive EV; this implies that the acceleration performance was improved by 7.96%. From the above results, it can be inferred that the two-speed transmission improves the acceleration performance of a front-wheel-drive EV more when the EV has a faster maximum velocity.

3.2 Rear wheel drive EV

Table 6 shows the simulation results of the 0-100 km/h time for the rear-wheel-drive EV. The iterative simulations were performed for the gear ratios from 3 to 12; Because the iterative simulations were performed based on a square matrix, such as Fig. 2, table 6 exhibits diagonal symmetry. The diagonal line of table 6 represents the 0-100 km/h time of the single-gear-ratio rear-wheel-drive EV. Table 7 shows the simulation results of maximum velocity for the rear-wheel-drive EV. The diagonal line of table 7 represents the maximum velocity of the single-gear-ratio rear-wheel-drive EV.

Table 8 shows the optimal gear ratio of the single-gear-ratio rear-wheel-drive EV. When the EV had a maximum velocity of over 170 km/h, the optimal gear ratio was 7, and the 0-100 km/h time was 10.04seconds. When the EV had a maximum velocity of over 170 km/h, the optimal gear ratio was 6, and the 0-100 km/h time was 10.68 seconds.

Table 4 Optimal gear ratio of the single gear ratio front wheel drive EV

Maximum velocity	Gear ratio	0-100 km/h time.
> 170km/h	7	10.04 Sec.
> 190km/h	6	10.68 Sec.

Table 5 Optimal gear ratio of the 2-speed gear ratio front wheel drive EV

Maximum velocity	Gear ratio	0-100 km/h time	Compare to single gear
> 170km/h	7 & 8	9.83 Sec.	- 0.21 Sec. (- 2.09%)
> 190km/h	6 & 8	9.83 Sec.	- 0.85 Sec. (- 7.96%)

Table 6 Simulation results of 0-100 km/h time for the rear wheel drive EV

0-100 km/h time of rear wheel drive EV, [sec]										
2nd gear / 1st gear	3	4	5	6	7	8	9	10	11	12
3	18.39	13.78	11.75	10.68	10.04	9.64	9.36	9.16	9.02	8.98
4	13.78	13.78	11.74	10.67	10.04	9.63	9.35	9.15	9.01	8.96
5	11.75	11.74	11.75	10.67	10.03	9.63	9.35	9.15	9.01	8.96
6	10.68	10.67	10.67	10.68	10.04	9.63	9.35	9.15	9.01	8.96
7	10.04	10.04	10.03	10.04	10.04	9.63	9.35	9.15	9.01	8.96
8	9.64	9.63	9.63	9.63	9.63	9.64	9.35	9.16	9.01	8.96
9	9.36	9.35	9.35	9.35	9.35	9.35	9.36	9.16	9.01	8.97
10	9.16	9.15	9.15	9.15	9.15	9.16	9.16	9.16	9.01	8.97
11	9.02	9.01	9.01	9.01	9.01	9.01	9.01	9.01	9.02	8.97
12	8.98	8.96	8.96	8.96	8.96	8.96	8.97	8.97	8.97	8.99

Table 7 Simulation results of maximum velocity for the rear wheel drive EV

Maximum velocity of rear wheel drive EV, [sec]										
2nd gear / 1st gear	3	4	5	6	7	8	9	10	11	12
3	200	201	201	201	201	201	201	201	201	201
4	201	201	201	201	201	201	201	201	201	201
5	201	201	201	201	201	201	201	201	201	201
6	201	201	201	199	199	199	199	199	199	199
7	201	201	201	199	172	172	172	172	172	172
8	201	201	201	199	172	151	151	151	151	151
9	201	201	201	199	172	151	135	135	135	135
10	201	201	201	199	172	151	135	122	122	122
11	201	201	201	199	172	151	135	122	111	111
12	201	201	201	199	172	151	135	122	111	102

Table 8 Optimal gear ratio of the single gear ratio rear wheel drive EV

Maximum velocity	Gear ratio	0-100 km/h time
> 170km/h	7	10.04 Sec.
> 190km/h	6	10.68 Sec.

Table 9 Optimal gear ratio of the 2-speed gear ratio rear wheel drive EV

Maximum velocity	Gear ratio	0-100 km/h time	Compare to single gear
> 170km/h	7 & 12	8.96 Sec.	- 1.08 Sec. (- 10.76%)
> 190km/h	6 & 12	8.96 Sec.	- 1.72 Sec. (- 16.10%)

Table 9 shows the optimal gear ratio of the two-speed-gear-ratio rear-wheel-drive EV. When the EV had a maximum velocity of over 170 km/h, the optimal two-speed gear ratio was 7 & 12, and the 0-100 km/h time was 8.96 seconds, which is 1.08 seconds faster than the 0-100 km/h time for the single-gear-ratio rear-wheel-drive EV. Thus, it can be concluded that the acceleration performance was improved by 10.76%. When the EV had a maximum velocity of over 170 km/h, the optimal two-speed gear ratio was 6 & 12, and the 0-100 km/h time was 8.96 seconds, which is 1.72 seconds faster than the 0-100 km/h time of the single-gear-ratio front-wheel-drive EV. Thus, it can be concluded that the acceleration performance was improved by 16.10%.

From tables 5 and 9, it can be inferred that the two-speed transmission can improve the acceleration performance of both the front- and rear-wheel-drive EVs. However, the acceleration performance improvement of real-wheel-drive EVs is significantly better than that of front-wheel-drive EVs.

4. Conclusion

In this study, the acceleration performance improvement of EVs owing to a two-speed transmission was analyzed. An EV simulator was developed to analyze the EV acceleration performance. From the simulation results, it was found that if the maximum velocity is over 170km/h, the acceleration performance of front-wheel-drive EVs can be improved by 2.09% by using a two-speed transmission. However, if the two-speed transmission is applied to rear-wheel-drive EVs with the same maximum velocity, the acceleration performance can be improved by 10.76%; this is because the rear wheels can deliver more traction force. Thus, rear-wheel-drive EVs have a higher gear ratio. It was also observed that if the maximum velocity is over 190km/h, the acceleration performance of front-wheel-drive EVs can be improved by 7.96% by using a two-speed transmission. However, if the two-speed transmission is applied to rear-wheel-drive EVs with the same maximum velocity, the acceleration performance can be improved by 16.10%. From the above results, it can be inferred that the two-speed transmission can improve the acceleration performance more when the EVs have a faster maximum velocity. Furthermore, the two-speed transmission can improve the acceleration performance of rear-wheel-drive EVs more than that of front-wheel-drive EVs.

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References

1. Lee, J. G., Kim, S. H., Han, S. G., Shin, Y. I. and Song, C. K., "Design of a Reducer Gear for Small Electric Vehicles," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 19, No. 9, pp. 116-121, 2020.

2. Kim, J. M., "Comparative Study of Acceleration Performance for High Performance Electric Vehicles: Model S and Taycan," Transactions of KSAE, Vol. 29, No. 5, pp. 419-425, 2021.
3. Kim, J. M., "Comparative Study of Powertrain Loss and Efficiency for the Electric Vehicle and Internal Combustion Engine Vehicle", Journal of the Korean Society of Manufacturing Process Engineers, Vol. 18, No. 7, pp. 29-35, 2019.
4. Kwon, H. S., "Assemblability Analysis of the Kinematic Configurations of Ravigneaux-Type Automatic Transmissions," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 18, No. 3, pp. 49-58, 2019.
5. Cho, S. P., Lee, D. G., Kim, L. S., Xu, Z. Z. and Lyu, S. K., "Study of the Transmission Error Prediction of a Five-speed Manual Transmission System," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 15, No. 2, pp. 66-71, 2016.
6. Lee, K. J. and Kim, J. M., "Power Flow Analysis for Manufacturing of Planetary Gears in a 8-Speed Automatic Transmission (I) : 1-3 Speeds," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 15, No. 5, pp. 48-56, 2016.
7. Sim, H. S., "A Study on an Electric Power System Design of a Small Electric Vehicle", Journal of the Korean Society of Manufacturing Process Engineers, Vol. 17, No. 1, pp. 89-94, 2018.
8. Park, J. Y., Shim, W. J. and Heo, S. J., "A Study of Tire Road Friction Estimation for Controlling Rear Wheel Driving Force of 4WD Vehicle," Transactions of KSAE, Vol. 24, No. 5, pp. 512-519, 2016.