Gearshift Strategy of a Two-Speed Dual-Clutch Transmission for Energy Efficacy of Electric Vehicles

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Abstract. In order to increase the energy efficiency of electric vehicles, the research related to controlling traction electric motors and controlling transmission system have been gathering more interest recently. The traditional electric vehicles use a one-speed gearbox. This transmission structure is simple but cannot achieve the best performance because most of the time the electric motor operates at the points where the efficiency is not the highest. Most electric vehicles today use gearboxes with multiple speeds. The transmission systems on traditional cars using internal combustion engines can be used for electric vehicles. In this paper, the author presents the research result on the gearshift strategy of a two-speed dual-clutch gearbox applied on electric vehicles for energy efficiency. The gearshift strategy takes into account the vehicle speed and drag forces.

Keywords: Electric vehicle · Energy efficiency · Gearshift strategy · Electric vehicle transmission · Two-speed gearbox

1 Introduction

Energy efficiency is an important performance criterion for vehicles in general, especially for electric vehicles (EV). EVs are limited in battery capacity and therefore require the optimal use of energy. Energy regeneration during braking, downhill, and optimal energy management are the problems that EVs face. In literature, there has been some research to improve the efficiency of electric motor [2, 7], to improve energy efficiency by optimal design of the transmission ratios [3–5] and design the gearshift strategies for energy efficiency of an electric vehicle. An EV with the multi-gear transmission can enhance both dynamic and economic performances [4]. The EV with a four-gear transmission can save up to 30% energy. [3] shows that only by designing the optimal transmission ratios, energy can be saved up to 15%. In [6], the authors present a graphical method for the development of dynamic shift schedules. Accordingly, with the drag force of vehicle, the point of transition is determined. In this paper, the authors

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develop a new graphical method for an economic gearshift strategy of electric vehicles. The gearshift strategy takes into account the vehicle speed and drag forces.

2 Gearshift Strategies Modeling

2.1 Calculating the Gear Ratios

A vehicle is designed to tolerate different driving conditions on the road. That means the vehicle can move on the road if the traction generated on the active wheels matches the total resistance acting on the vehicle at that time. The traction force generated at the wheels is supplied by the electric traction motor through the transmission. According to the design point of view, the gear ratios are calculated to meet the vehicle's operating conditions, that means it is necessary to determine the driving forces acting on the vehicle and the required speed that the vehicle can achieve. Therefore, the necessary parameters for the vehicle need to be provided in full to serve the gear ratio calculation. In this study, the vehicle's input parameters are provided as follows: vehicle mass, $m = 1400$ kg; wheel radius, $r_d = 0.26\,\text{m}$; maximum on-road drag coefficient,$\psi_{\max} = 0.4$; frontal area, $F = 1.510\,\text{m}^2$; air resistance coefficient, $K = 0.18\,\text{Ns/m}^4$; transmission efficiency, $\eta = 0.95$.

To perform this study, the authors chose an electric motor model that can meet common road conditions on passenger vehicles with a small weight. The selected electric motor can achieve a maximum torque of 200 N.m and achieve a speed of 8000 rpm as shown in Fig. 1.

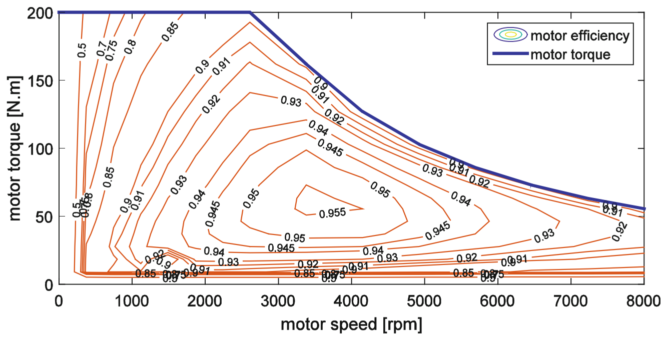


Fig. 1. Efficiency map of electric motor

The powertrain can increase the initial torque of the drive motor, and adjust the vehicle speed through the transmission ratio. The transmission ratio divides into two parts: the gearbox ratio and the final drive ratio. For a two-speed gearbox, the first gear ratio can be calculated as:

$$i_{tr1} = r_d mg\psi_{\max}/(T_{m\max}\eta) \tag{1}$$

and the second gear ratio equation is as follows:

$$i_{tr2} = 3.6\pi n_{m\max} r_d / (30 v_{\max}) \tag{2}$$

Where: g is the gravity acceleration, m/s^2; $T_{m\max}$ is the maximum torque of electric motor, $N.m$; $n_{n\max}$ is the maximum speed of electric motor, rpm; $v_{\max}$ is the maximum speed of vehicle, km/h.

For vehicles using a two-speed gearbox, each gear has a role. The first gear assures that the vehicle can move on the road with the required slope, and the vehicle can achieve maximum speed in second gear. Therefore, the electric motor is limited to a speed of 6000 rpm, in the high-efficiency region. The gear ratios are calculated as: the fist gear ratio is $i_{tr1} = 8.2$, and the second gear ratio is $i_{tr2} = 3.3$. For vehicles using a one-speed gearbox, in order for the vehicle to reach the required speed and slope, the engine speed used at its maximum speed is 8000 rpm, the gear ratio of the transmission is calculated as $i_{tr} = 4.48$.

2.2 Designing Gearshift Strategies

Assuming that the energy loss in the powertrain is constant, $\eta = 0.95$, and the vehicle moves without acceleration. Thus, the torque and speed of the drive motor required, T_{er}, n_{er} to equal the vehicle drag force equivalent at the time of consideration are calculated as follows:

$$T_{er} = i_{tr}\eta(mgf + KFv_t^2)/r_d \tag{3}$$

$$n_{er} = \pi v_t r_d/(30 i_{tr}) \tag{4}$$

Where v_t is the vehicle speed at the survey time. From Eqs. (3) and (4), it is clear that at the time of the survey, the speed of the drive wheel and the total drag force acting on the vehicle are specific figures.

Corresponding to each gear level selected, there are the corresponding torque and speed pairs. For each pair of torque and speed, the electric motor performance is different as shown in Fig. 2.

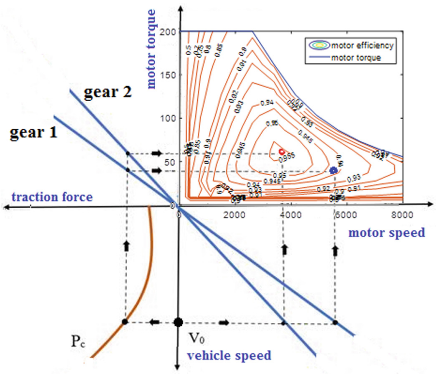


Fig. 2. Operating point of each gear level

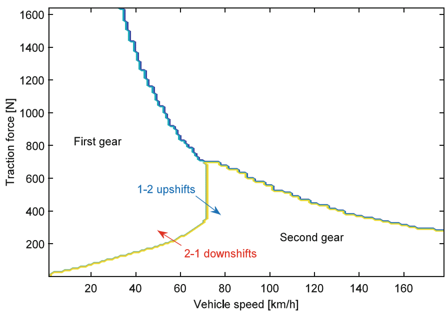


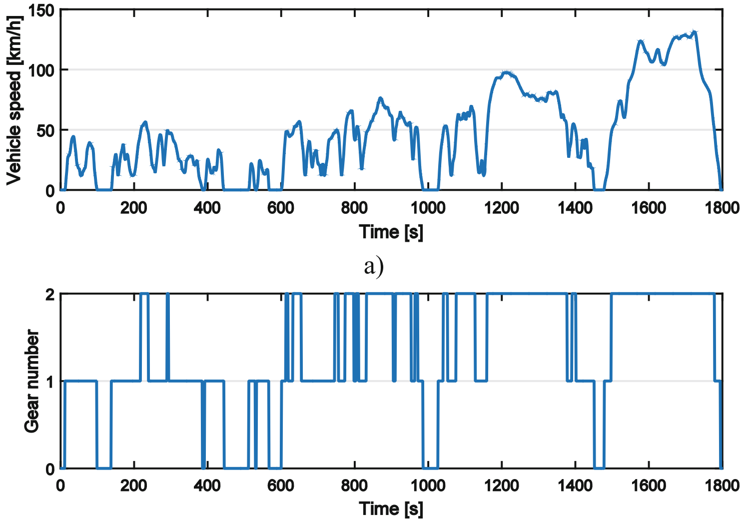
Fig. 3. Optimal operating region of each gear level of two-speed gearbox

According to the above arguments, directly comparing the performance of electric motors at the survey time with each gear level. From then, the controller can make a decision to choose the most relevant number. This is quite easy for current computers.

With the basic characteristics of the electric motor used for the survey, the top tractive torque on all of the active wheels can be reached at 1640 Nm, and the maximum speed of the vehicle is 178 km/h according to the input requirements. Thus, it is possible to identify the operating conditions of the engine, the conditions to succeed the drag on the road throughout the powertrain as shown in Fig. 3. In Fig. 3, the vehicle speed – traction force graph devices in two regions: first gear and second gear region. Once the working conditions of the vehicle are determined, the gearshift strategy can determine the best working region for each gear. In the first gear region, the engine will work with high efficiency when using first gear, the remaining region is optimal for the second gear.

3 Simulation Results and Discussion

The gearshift strategy design is tested and evaluated through a driving test cycle to determine the fuel consumption for an internal combustion engine or the energy required for an electric motor. In this study, the authors use the WLTP test cycle as input data for gearshift simulation (Fig. 4a).



a)

b)

Fig. 4. Gearshift strategy for two-speed gearbox

According to the WLTP test cycle, the vehicle is tested on a flat road. The gear number is selected depending on the vehicle speed and the resistance force conditions. In this simulation case, the gearshift strategy is shown in Fig. 4b. The simulation results in Fig. 5 show that the electric motor efficiency is improved by using a two-speed gearbox. The results showed that the average performance is 90% when using single-speed gearbox and 93% when using two-speed gearbox, improved by 3%.

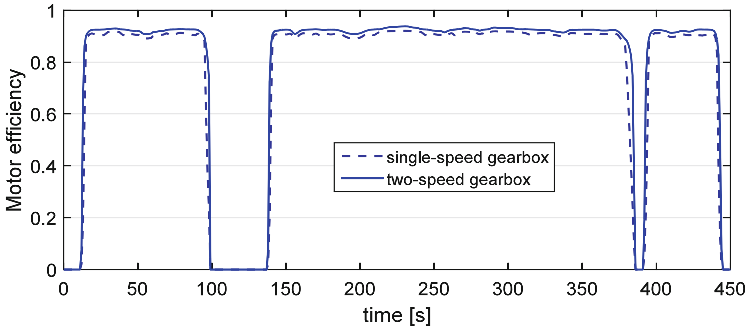


Fig. 5. The motor efficiency with a relevant transmission

For vehicles operating under harsher conditions in the WLTP test cycle, corresponding to each speed at the survey time, there will be an appropriate resistance force. When the vehicle operates in harsher conditions, drag force varies over a wide range, the two-speed gearbox has improved the efficiency. The controller selected the most reasonable number at each working time, to optimize the performance of the traction motor at that time as shown in Fig. 6. The graph shows clearly the compared results of the efficiency of the electric motors when using a single-speed gearbox or two-speed

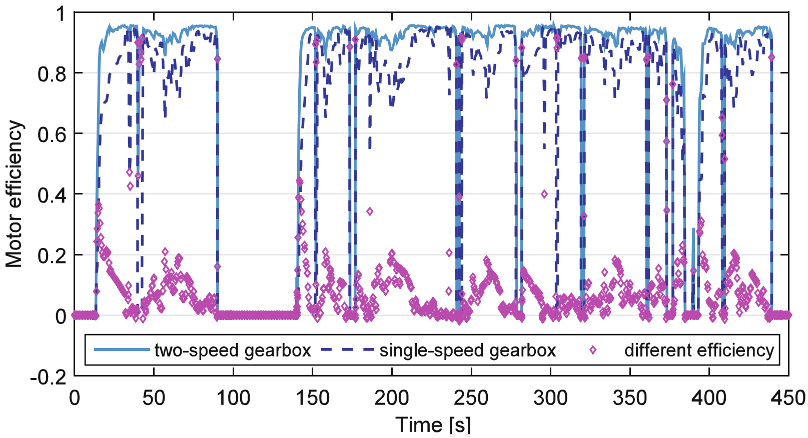


Fig. 6. The efficiency with the changing resistance

gearbox, with a two-speed gearbox much more efficient than a single-speed gearbox. The results show over the entire survey process, in this case, the average performance is 67% with a single-speed gearbox, and 76% with a two-speed gearbox, improved by 13%. There are certain areas where the performance can improve by over 50%.

4 Conclusion

The work aims to demonstrate the effectiveness of the two-speed powertrain used on electric vehicles by using the optimal control strategy. The authors calculated the gear ratios for the powertrain using the single-speed gearbox and the two-speed gearbox. The authors develop a gearshift strategy for the two-speed gearbox transmission system. A gearshift map is developed. The simulation results show that the average efficiency of the drive motor increased significantly compared to the case of a single-speed powertrain. When simulating on a harsher road, the motor efficiency can be improved by 13%. There are certain areas where the motor efficiency rose to 50%. However, when simulating on a good road, with certain resistance conditions, shows that motor efficiency is only increased by 3%.

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