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Comparative study of single-motor and dual-motor electric-driven mechanical transmission with optimized parameters for a light truck

Ziwang Lu[1], Guangyu Tian[1], Yiwen Sun[1], Runfeng Li[1]
[1]*Guangyu Tian (corresponding author) State key laboratory of safety and energy*
School of Vehicle and Mobility, Tsinghua Univeristy, China, 100084, tian_gy@tsinghua.edu.cn

Executive Summary

Dual-motor electric-driven mechanical transmission (DEMT) is a new powertrain architecture to solve the energy-saving and dynamic problems in electric vehicles. Parameter optimization is significant in solving those problems. However, few researchers account for the drive motor parameter optimization. In this paper, both the drive motor parameters and transmission parameters are optimized by the genetic algorithm. Both parameters of DEMTs with different gears (1, 2, 3, 4, 5 and ideal CVT) and single-motor electric-driven mechanical transmission (SEMT) with different gears (1, 2, 3, 4, 5 and ideal CVT) are optimized. The energy consumption results show that DEMTs have both better economic and dynamic performances than SEMTs. SEMTs with 2 gears and DEMTs with 1+2 gears or 2+2 gears are better choices for the light truck accounting for economic, dynamic and structural performances.

Keywords: Electric drive, Electric vehicle, Optimization, Powertrain, Transmission, Truck

1 Introduction

Electric vehicles are massively invading the roads accounting for the climate change and environment pollution concerns [1, 2]. With a transmission, the electric motor can not only have larger torque range and speed range but also better economics and dynamics[3]. A single-motor electric-driven mechanical transmission (SEMT) with 2 gears is shown in Fig. 1a. To eliminate the power interruption and improve the operation efficiency, the architecture of a dual-motor integrated to the transmission is studied extensively these days[4, 5]. A dual-motor electric-driven mechanical transmission (DEMT) with 2+2 gears is shown in Fig. 1b. A comparative study between DEMT with 1+1 gears and SEMT with 1 or 2 gears is done in [6, 7]. The parameters are selected by rules. Simulation results show that the DEMT with 1+1 gears has better efficiency performance than the SEMT with 1 or 2 gears. Hu et al. proposes a method to obtain the overall efficiency map of the dual-motor transmission system [8]. Lin et al. apply the dynamic programming and k-means cluster algorithm to solve the online optimal gear-shift control strategy [9]. Parameter matching and control strategy are studied in [10]. The parameters are selected based on vehicle dynamic requirements. Most researchers select powertrain system parameters based vehicle dynamic requirements or optimize gear ratio parameter. However, few researchers optimize drive motor parameters. In this paper, both gear-ratio parameter and drive motor parameters including normal speed and maximal torque are optimized based on the genetic algorithm (GA) to pursue a better economic performance while satisfying the vehicle dynamic requirements.

2 Mechanical system

The mechanical structure studied in this paper is shown in Fig. 1b. The mechanical transmission has two inputs. Each one is connected to one drive motor, which can perfectly extend the torque and speed ranges of the drive motor.

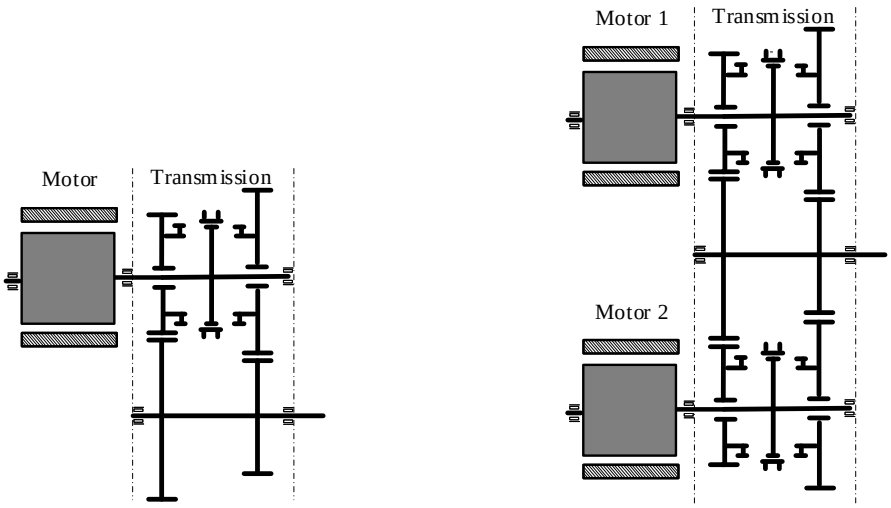

Figure 1: Mechanical structure. (a) SEMT with 2 gears. (b) DEMT with 2+2 gears.

3 Problem formulation

The objective of this problem is to minimize the energy consumption. The cost function is given as:

$$J = \sum_{k=1}^{N} \left(P_{m1}^{k} + P_{m2}^{k} \right) dt \tag{1}$$

where P_{m1}^{k} and P_{m2}^{k} is the power of motor 1 and motor 2 respectively.
The variables need to be optimized in SEMT are:

$$X_S = [n_o, T_m^{max}, i_{g1}, i_{g2}, ...]$$

where n_o and T_m^{max} are the normal speed and maximal torque of the drive motor. $i_g1, i_g2, ...$ are the transmission ratios.
The variables need to be optimized in DEMT are:

$$X_D = [n_o^{m1}, T_{m1}^{max}, n_o^{m2}, T_{m2}^{max}, i_{g1}^{m1}, i_{g2}^{m1}, ..., i_{g1}^{m2}, i_{g2}^{m2}, ...]$$

where n_o^{m1} and T_{m1}^{max} are the normal speed and maximal torque of the drive motor 1. $i_{g1}^{m1}, i_{g2}^{m1}, ...$ are the transmission ratios of the transmission connected to the drive motor 1. n_o^{m2} and T_{m2}^{max} are the normal speed and maximal torque of the drive motor 2. $i_{g1}^{m2}, i_{g2}^{m2}, ...$ are the transmission ratios of the transmission connected to the drive motor 2.
During the simulation, the parameters should satisfy the dynamic requirements of the test cycle shown in Fig. 2. A light truck is chosen, whose parameters are in Table. 1.

4 Results and discussion

The optimization problem is solved by the genetic algorithm. Both parameters of SEMTs with different gears (1, 2, 3, 4, 5 and ideal CVT) and DEMTs with different gears (1, 2, 3, 4, 5 and ideal CVT) are optimized. The comparative studies on dynamics and economics are as following.

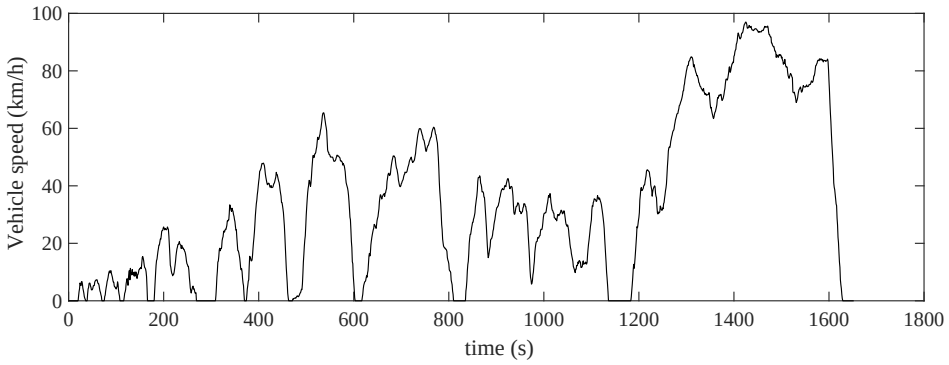

Figure 2: China heavy-duty commercial vehicle test cycle for light truck (CHTC-LT)

Table 1: Vehicle parameters

Parameters	Value	Unit
Vehicle mass	4500	kg
Final drive ratio	6.24	-
Wheel radius	0.43	m
Rolling resistance coefficient	0.0165	-
Aerodynamic coefficient	0.85	-
Wind area	5	m^2

4.1 Comparative study on economics

Fig. 3 shows the economic comparison between the SEMT with different gears and the DEMT with different gears. We can find that (1) the DEMT has better economic performance than SEMT, (2) the decline ratio of the energy-consumption becomes slow when the SEMT comes with 2 gear and the DEMT comes with 1+2 gears or 2+2 gears.

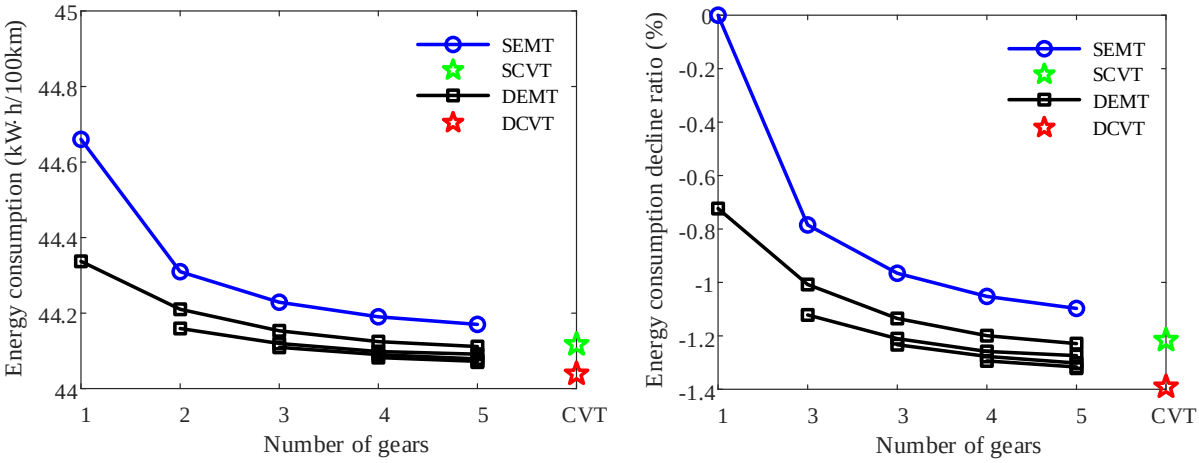

Figure 3: Economic comparison.

4.2 Comparative study on dynamics

Fig. 4 and 5 show the maximal vehicle speed and acceleration time between the SEMT with different gears and DEMTs with different gears. We can find that the DEMT has higher maximal vehicle speed and less acceleration time than the SEMT, which means the DEMT has better dynamic performance than the SEMT.

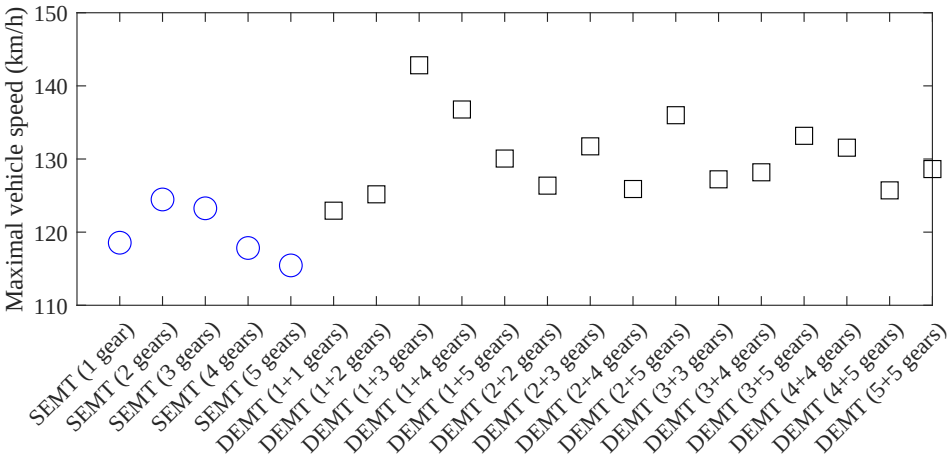

Figure 4: Comparison of maximal vehicle speed.

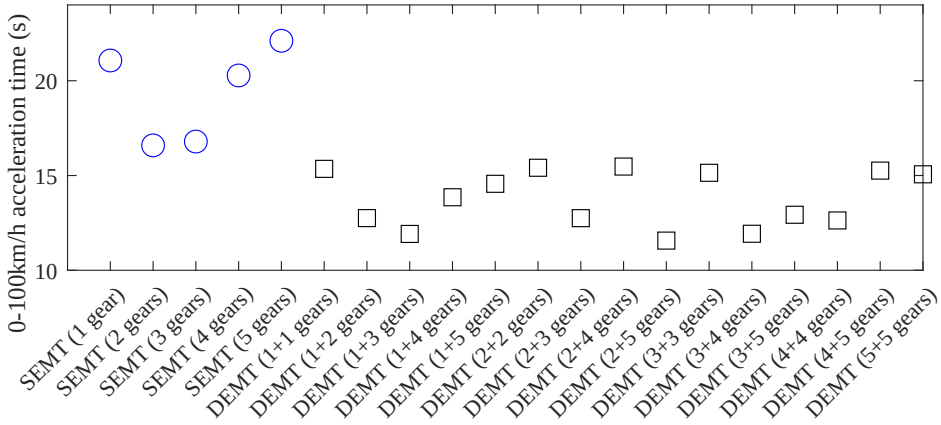

Figure 5: Comparison of acceleration time.

5 Conclusion

According to the results solved in Section 4, the DEMT has better economic and dynamic performance than the SEMT. The SEMT with 2 gears and the DEMT with 1+2 gears or 2+2 gear are better choices for the light truck accounting for a simple mechanical structure.

Acknowledgments

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Presenter Biography

Ziwang Lu received his B.S. degree in School of Mechanical Engineering, Beijing Institute of Technology in 2015 and his Ph.D. degree in School of Vehicle and Mobility, Tsinghua University in 2021. During that time, he was a joint Ph.D. student with the Department of Energy Resources Engineering, Stanford University, sponsored by the China Scholarship Council from May 2019 to July 2020.

He is currently a postdoctoral research fellow as a Shuimu Tsinghua Scholar in the State Key Laboratory of Automotive Safety and Energy, School of Vehicle and Mobility, Tsinghua University. His research interests include mechanical transmission control and energy management.