Research on Efficiency Improvement of Automotive Transmission Systems

Shenshen Liang*

College of Mechanical and Aerospace Engineering, Jilin University, Changchun, 05000, China

Abstract. This review article examines research on efficiency improvement in automotive transmission systems. Current studies in this field categorize transmission energy losses into three main sources: mechanical components (such as gears, bearings, seals, and lubrication-related friction), electromechanical coupling systems (including motors, power electronics, and energy conversion interfaces), and losses arising from control and management strategies at the system level. Among these, the third category remains comparatively underexplored, with significant opportunities for further investigation — particularly in areas such as predictive control, thermal management, and real-time optimization under dynamic driving conditions. Furthermore, a substantial body of literature focuses on torque and rotational speed as key control variables, operating on the premise that system-level efficiency can be enhanced through optimized coordination of these two parameters under varying operating conditions. By synthesizing findings across these areas, this review highlights both established approaches and research gaps, with the goal of guiding future work toward more holistic, integrated efficiency strategies in next-generation transmission systems.

1 Introduction

The "Technology Roadmap 2.0 for Energy-Saving and New Energy Vehicles" released by the China Society of Automotive Engineers clearly states that by 2035, the sales of energy-saving vehicles (with hybrid technology as the core) and new energy vehicles will each account for 50% [1]. Against the backdrop of global energy transition and climate action, automotive energy sources are gradually shifting from traditional gasoline-driven to pure electric or hybrid-driven, which has also brought about tremendous changes in automotive transmission systems. Traditional transmission systems centred on three-axis gearboxes cannot adapt to pure electric and hybrid vehicles, thus leading to the emergence of transmission systems centred on planetary gear sets and motor transmission systems adapted for pure electric drive. Under the general direction of energy conservation and emission reduction, the research is necessary given that the transmission system can currently consume 15% to 25% of the vehicle's output energy [2]. If people can reduce the energy loss in the transmission system, it will greatly help reduce the overall energy loss of the vehicle. Since the thermal efficiency of the engine has almost reached the upper limit of current materials

* Corresponding author: liangss9925@jlu.edu.cn

science and thermodynamics, people can only improve energy utilization efficiency by reducing other losses.

At present, this research on improving the efficiency of transmission systems mainly focuses on the following directions: 1. Improvement of transmission gear shape, materials, and lubricating oil, which belongs to mechanical improvement. 2. Optimization of the electromechanical coupling system, mainly researching better coordination between the motor and output physical parameters. 3. Optimization of system control strategies and energy management. In traditional gasoline-powered manual transmission vehicles, this is accomplished by humans through a three-axis gearbox, while in automatic transmission vehicles and hybrid vehicles, it is automatically performed by the vehicle through torque distribution of planetary gear sets. Current research mainly focuses on the improvement of mechanical transmission components and the innovation of hybrid system configurations (especially in terms of power split. However, research on system control strategies and energy optimization is not as extensive as the previous two areas, and the optimization of power split efficiency under transient operating conditions is not sufficiently in-depth. In hybrid transmission systems, efficiency improvement requires an overall consideration of multiple factors such as mechanics, electricity, and thermal management. Therefore, existing research still lacks an integrated study that unifies these conditions.

In the following sections, this article will first discuss the composition and mechanism of transmission system efficiency loss, then explore key technical directions such as mechanical transmission optimization, electromechanical coupling configuration innovation, intelligent control strategies, and new materials and processes in separate chapters, and finally summarize technical bottlenecks and prospect innovative paths for interdisciplinary integration, aiming to provide a systematic reference for scholars and engineers in the field.

2 Mechanical components

Research on the mechanical components has accumulated the most over the past years. Relevant studies classify them into two categories: operating condition factors and intrinsic factors. Lubricating oil viscosity (determined by oil temperature and lubricating oil type, oil immersion depth of the oil-stirring gear, input torque, output speed, etc., all belong to operating condition factors; while factors determined by the transmission system itself, including bearing type, gear structural parameters, and the assembly structural relationship between gears and bearings, etc., are intrinsic factors. This part already has extremely precise mathematical models. Regarding the geometric shapes and materials of gears and bearings, through long-term production and research processes, solutions that balance cost, processing, and efficiency have been developed [3]. Meanwhile, other studies have shown that efficiency increases with load torque, but the impact of rotational speed on efficiency is not significant [4].

An interesting review studied the development of hydraulic transmission systems in commercial vehicles. A hydraulic transmission system is a variable speed technology system that uses fluid motion to transmit kinetic energy. This technology can achieve energy conversion through the cooperation of several impellers, thereby completing the flexible connection between the load and the power system. The main components of the hydraulic transmission system are the torque converter and the hydraulic retarder [5]. The torque converter can reduce the impact load between the engine and the transmission when the vehicle starts, allowing the vehicle to adapt to various working conditions. Its working principle is that the oil circulates among the turbine, pump wheel, and guide wheel to transmit energy. During the operation of the torque converter, the oil not only forms eddies around the impeller, turbine, and guide wheel but also forms a circulating flow around the transmission shaft. It is subject to these two periodic fluid loads, as well as centrifugal loads and external loads. At the same time, due to the influence of working conditions and environment, the temperature field and structural field between the impellers also affect the working performance of the torque converter. The author believes that the high-efficiency operating range of this device is relatively narrow, and power waste is prone to occur when working conditions change. The main defects are easy leakage, abnormal oil temperature, structural deformation, and damage. Regarding the structure of the torque converter and the optimization of the internal flow field, existing studies have revealed the correlation between the pressure pulsation characteristics of the torque converter and operating parameters and structural design. However, there are still deficiencies in the flow field evolution law under multi-condition coupling, the global constraints of structural optimization, and the description of transient unsteady effects. It is worth noting that previous extensive research has produced the lock-up and unlock technology for torque converters. This technology can instantly switch between hydraulic transmission and traditional mechanical transmission, thereby reducing losses caused by energy conversion. However, such lock-up clutches still have limitations such as high lock-up force requirements, strong vibration and impact, long switching time, and poor reliability and comfort. Therefore, in the face of vehicle working conditions with high load, strong impact, and frequent shifting, people still need torque converters with functions such as clutch lock-up and torsional vibration damping.

The hydraulic retarder achieves wear-free braking by directly converting the vehicle's kinetic energy into heat energy of the brake fluid. It can directly eliminate the brake failure problem caused by overheating of the brake pads, which is prone to occur after long-term braking with traditional braking methods. However, this hydraulic retarder pumps air into the retarder in the non-braking state, resulting in a large amount of additional energy consumption and noise. The energy loss caused by this situation is called idling loss. To address this, the first method is to suppress air pumping by physically blocking the airflow channel, but this method has limitations such as reduced reliability, delayed switching of working states, and mechanical wear. Another method is to install a flow field disturbance device to reduce energy loss caused by air, but this method will interfere with the fluid flow during normal braking. At the same time, the existing physical theories for flow field prediction and control are not yet perfect, which greatly limits the application of this method. In addition, the heat dissipation device of the hydraulic retarder needs to be redesigned, which is also one of the application limitations. In conclusion, the hydraulic transmission system avoids some pain points of the traditional transmission system by virtue of a completely different principle but also creates some pain points of its own.

3 Electromechanical coupling system

Regarding the control efficiency part of the electromechanical coupling system. It can be found that part of it is the loss of the motor and generator themselves, such as copper loss caused by winding resistance, iron loss caused by core hysteresis and eddy current, and mechanical loss caused by other mechanical friction. Using high-efficiency electromagnetic materials to reduce these losses can significantly reduce the overall loss of pure electric vehicles or hybrid vehicles. In current new energy electric vehicles and hybrid vehicles, there is a bidirectional energy flow: energy is converted from the engine into mechanical energy, and during energy recovery, mechanical energy flows from the generator to energy storage devices such as batteries. The losses generated in this process are mostly copper loss and iron loss, where copper loss is generated by the motor stator, iron loss by the motor rotor, and mechanical loss by bearing friction. These three together constitute the loss of the motor itself, and studies have shown that copper loss is greater than iron loss. The stator current and stator resistance have a greater impact on copper loss. The stator resistance can be reduced by optimizing the stator winding design and using new materials. As for the stator current, according to the motor torque equation, the stator current is inversely proportional to the permanent magnet flux linkage. Therefore, studies have shown that the stator current can be reduced by optimizing the arrangement of permanent magnets and increasing the permanent magnet flux linkage, thereby reducing copper loss [6]. Another approach is to reduce the stator current through motor control algorithms. Currently, the most widely used and mature one is the MTPA control algorithm, which aims to control the output torque of the motor. It uses Hall sensors to detect the three-phase current of the three-phase motor, converts it into two orthogonal currents in the two-phase rotating coordinate system, and reasonably configures the magnitude of these two currents to minimize the stator current while outputting a certain torque. Another method is model predictive control (MPC), which can directly handle various constraints of the entire system, achieve fast dynamic response, and optimize torque and flux linkage simultaneously. Iron loss consists of core loss and permanent magnet loss. Iron loss can be reduced at the material level by selecting silicon steel sheets with lower loss rate and higher magnetic permeability. Studies have shown that amorphous alloy materials may have such characteristics, with more obvious advantages under high-speed and high-frequency working conditions. Iron loss can also be reduced at the design level through motor winding structure and motor flux barrier design.

The electromechanical coupling system also has electronic control losses, with the conduction losses and switching losses of power devices (IGBT/SIC MOSFET) being the core. The higher the switching frequency, the greater the switching losses; however, this helps reduce motor current harmonics and iron losses, presenting a trade-off relationship. To reduce electronic control losses, people can first adopt wide bandgap semiconductors, using SIC—a semiconductor material superior to pure Si in terms of bandgap width, electric field strength, saturated electron mobility, melting point, and thermal conductivity—to manufacture electronic control hardware. This can effectively enhance the power and efficiency of the entire motor system while increasing the switching on and off rates. Secondly, people can also employ soft switching technology. The reduction of losses during the state switching of power devices is achieved through a resonant process. Precise timing devices are used to enable switches to switch states within specific resonant cycles. Integrated inductors, capacitors, and other components are used to construct auxiliary commutation networks, thereby achieving zero-voltage switching-on or zero-current switching-off, eliminating induction phenomena during state switching, and reducing low power losses of devices as well as electromagnetic noise.

On another front: the torque distribution problem of planetary gears in transmission devices of electric vehicles and hybrid vehicles. Studies have pointed out that the widely used direct yaw moment control has limitations on vehicle stability, causes a certain loss of vehicle speed, and affects the driver. In contrast, torque vectoring distribution control technology can distribute torque from the perspectives of vehicle handling stability and economy, showing good prospects. Meanwhile, electronic limited-slip differentials improve the vehicle's low-adhesion possibility; however, since they can only unidirectional transfer torque between the wheels on both sides of the differential, they are suitable for application on good road surfaces and have currently found applications in four-wheel-drive vehicles [7].

Studies have shown that mechanical losses, electronic control losses, and motor losses have different impacts under different operating conditions. Mechanical losses are relatively large under high-speed and low-torque conditions; electronic control losses are relatively large under low-speed and low-torque conditions; and motor losses are relatively large under low-speed and high-torque conditions. Additionally, the use of low-friction bearings and low-viscosity oils can reduce mechanical power losses, expand the high-efficiency region, and increase the maximum efficiency by approximately 0.9% [6].

4 Control and management loss of the entire system

Regarding the control and management loss part of the entire system. A large number of studies have also been conducted, and after the emergence of neural network algorithms, research has been carried out to use neural network algorithm iterative simulation to find the optimal solution. On the one hand, people can improve the efficiency of the transmission system by studying vehicle driving strategies. For example, a study shows that the "acceleration-gliding" driving strategy of electric vehicles has a slightly higher transmission system efficiency than the traditional constant-speed cruise driving strategy. The study also indicates that people can adopt different driving strategies under different driving conditions and construct an energy consumption-minimizing driving strategy by considering multi-objective genetic algorithms [8]. The above research adopts a common approach, establishing appropriate energy management strategies through manual input of driving styles and working condition identification. However, this method heavily relies on manually pre-input data and has significant limitations when facing complex working conditions in real driving; therefore, people hope to use artificial intelligence for real-time regulation.

There is a study on mathematical modelling of the efficiency of pure electric vehicle transmission systems based on the principle of BP neural network algorithm. There are a motor efficiency neural network model that inputs motor speed and torque and outputs motor efficiency, and a transmission efficiency neural network model that inputs lubricating oil temperature, transmission input torque, input torque, and outputs transmission efficiency. The efficiency comparison of two gears is studied. The study concludes that when the torque is less than a certain value, the efficiency of the low gear is higher than that of the high gear at the same speed; when the torque is higher than a certain value, the efficiency of the high gear is higher than that of the low gear at the same speed. In this regard, there have been studies hoping to control the vehicle transmission system through neural network systems. This is also a research direction with broad market and great application prospects in the future [9].

5 Conclusion

People have made significant progress in the research on automotive transmission systems. In terms of mechanics, people have not only conducted very comprehensive research on traditional transmission systems but also developed new hydraulic transmission systems and made great progress in this area. In terms of electromechanical coupling systems, this research direction overlaps with the motor direction to a certain extent, but people focus more on the connection between system electrical parameters and physical parameters such as torque. However, in terms of the control and management losses of the entire system, people still need more driving strategies that can be applied to complex actual driving conditions, and it is necessary to introduce artificial intelligence into the research. It can be noted that many researchers mainly focus on torque and speed in their studies, believing that these two factors can mainly affect the efficiency of the automotive transmission system. Through these studies, people can further optimize the energy distribution and power output of the vehicle, thereby reducing the energy loss of the vehicle. I am delighted with the vigorous development of the automotive industry.

References

1. Ministry of Industry and Information Technology, Ministry of Finance, & State Taxation Administration. Announcement on technical requirements for new energy vehicle products eligible for vehicle purchase tax exemption, No.32 (2023).
2. X. Su, H. Xiao, G. Yang, et al. Efficiency analysis and development trend of hybrid electric vehicles. Machine Tool & Hydraulics **39**, 57-58, 85 (2011).
3. W. Wang, Y. Mo, M. Tian, et al. Efficiency modelling and experimental verification of micro vehicle transmission system. Journal of Wuhan University of Technology **34**, 137–141 (2012).
4. J. Su. Research on efficiency improvement of electric vehicle transmission system. New Energy Vehicles, 100-102 (2016).
5. Z. Zhang, W. Wang, J. Hui, et al. Review of hydraulic transmission system for commercial vehicles. Journal of Chang'an University (Natural Science Edition) **46**, 1-19 (2025).
6. C. Huang, W. Zhang, Y. Li, et al. Analysis and optimization of influencing factors on electromechanical coupling system efficiency of hybrid electric vehicles. Journal of Chongqing University of Technology (Natural Science) **38**, 250-259 (2024).
7. J. Wang, B. Yang, Q. Wang, et al. Review on development of torque directional distribution technology for vehicles. Journal of Mechanical Engineering **56**, 92-104 (2020).
8. K. Zhang, M. Ouyang, L. Xu, et al. Energy-saving potential of pulse-and-glide (PNG) driving strategy for pure electric vehicles. Journal of Automotive Safety and Energy **5**, 192-200 (2014).
9. K. Chen, H. Li, X. Zhao, et al. Modelling and analysis of pure electric vehicle transmission system efficiency based on BP neural network. Journal of Mechanical Design and Research **37**, 180-185 (2021).