Research on Energy Flow Testing and Optimization of Pure Electric Vehicles

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Abstract

In recent years, new energy vehicles have achieved leapfrog development, yet energy consumption performance remains a critical bottleneck affecting user experience. The energy consumption issue in electric vehicles is essentially a concentrated reflection of the efficiency of energy conversion, storage, and utilization under complex working conditions and system interactions. For example, the remaining driving range is typically estimated dynamically based on instantaneous energy consumption. Factors such as rapid acceleration, air conditioning use, and low-temperature environments can easily cause a sharp drop in the displayed range, leading to range anxiety among users. Additionally, comfort features such as large screens, premium audio systems, ambient lighting, and seat heating/ventilation continuously consume electrical energy. Against this backdrop, energy flow testing has become an important method for unveiling the "black box" of energy transfer and breaking down macroscopic range anxiety into specific optimizable components. By testing and analyzing the energy flow within the vehicle, high-loss nodes can be accurately identified, thereby providing a clear basis for system-level energy efficiency optimization. This paper takes a pure electric heavy-duty truck as the research subject, conducts real-vehicle energy flow testing and in-depth analysis, with the aim of providing insights for optimizing the vehicle's energy management strategy.

Keywords

Energy Consumption; Energy Flow Testing; Energy Management.

1. Introduction

With the transformation of China's energy system and continuous breakthroughs in new energy technologies, the new energy vehicle industry in China has entered the fast lane of development. In January 2026, the China Association of Automobile Manufacturers announced that by 2025, China's automobile production and sales will both exceed 34 million units, setting a new historical high. The production and sales of new energy vehicles have exceeded 16 million units, and the proportion of new energy vehicle sales in China has exceeded 50%. Specifically, by 2025, China's automobile production and sales will reach 34.531 million and 34.4 million units respectively, with year-on-year growth of 10.4% and 9.4%, respectively, ranking first in the world for 17 consecutive years. The production and sales of automobiles have maintained a scale of over 30 million units for three consecutive years. The release of new kinetic energy is accelerating, with the production and sales of new energy vehicles reaching 16.626 million and 16.49 million respectively, an increase of 29% and 28.2% year-on-year, ranking first in the world for 11 consecutive years [1].

In 2025, the “two new” policies will be strengthened and expanded, with a high concentration of new products launched by enterprises, continuous release of terminal demand, and unexpected growth in automobile production and sales. However, the range anxiety problem of new energy vehicles still exists. For new energy heavy-duty trucks, the driving range is not only about how far the vehicle can run, but also a reflection of operational economy.

2026, as the starting year of the 15th Five Year Plan, is a crucial stage in refining the macro “planning map” into feasible “construction drawings”, and energy flow optimization technology is an important part of this “construction drawing”. One of the core goals of the 15th Five Year Plan is to promote the green and low-carbon transformation of the automotive industry, which is highly consistent with the fundamental purpose of energy flow optimization research.

2. Concept and Significance of Automotive Energy Flow

2.1. The Concept of Energy Flow in Automobiles

The concept of energy flow in a car refers to the entire path and process of energy transmission, conversion, distribution, and utilization within the car, from the source to final consumption or recovery. It is essentially a dynamic tracking and quantitative analysis of the energy transfer chain in automobiles, aimed at answering a fundamental question: “Where does every added energy ultimately go?”.

2.2. The Significance of Energy Flow Analysis in Automobiles

The core goal of vehicle energy flow testing and optimization is to maximize the efficiency of vehicle energy utilization and minimize energy consumption and carbon emissions. This is the specific technical means to implement the national "dual carbon" strategy and reduce carbon emissions in the transportation sector.

The most direct goal of vehicle energy flow analysis is to improve the overall energy efficiency and driving range of the vehicle. For automotive design and engineering development, energy flow analysis can locate energy loss “black holes” and intuitively identify where energy is located; At the same time, it can optimize the matching of the power system, accurately quantify the energy consumption, conversion efficiency, and losses of various links such as the engine/motor, battery, and transmission system, and provide a data basis for system selection and parameter calibration.

Range and battery life are the core concerns of consumers for pure electric vehicles. By optimizing energy flow, the vehicle's range can be significantly improved, and its degradation can be slowed down through intelligent management of the battery. This directly responds to the core demand of the market for new energy vehicle products and is the foundation for the sustained and healthy development of the industry.

Vehicle energy flow analysis is also a core tool for developing and validating energy management strategies (how to use electricity, when to use oil, when to recover braking energy) to ensure that the vehicle operates in an optimal or balanced state under any operating conditions.

3. Energy Flow Testing and Analysis

3.1. Test Prototype Vehicle

Table 1. Main Parameters of Sample Vehicle

Number	*Name*	*Parameter*
1	Actual maximum total mass(t)	45
2	Rated power of drive motor (kW)/Crest value	270/405
3	Rated voltage of battery(V)	618.24
4	battery level(kWh)	281.91/456Ah

This article selects a pure electric heavy-duty truck as the test sample, which is a 6 × 4 rear wheel drive vehicle. The main parameter information is shown in Table 1. Among them, the power battery is a 281.91kWh lithium iron phosphate battery, which adopts a liquid cooled dual battery solution; 270kW permanent magnet synchronous motor is selected as the motor.

3.2. Testing Environment and Equipment

The energy flow test is conducted on an indoor hub with an ambient temperature regulator[2], All signals are collected in the same time domain, including voltage, current, temperature, flow rate, pressure, CAN, and other signals. The main testing equipment is shown in Table 2.

Table 2. Main testing environment and equipment

Number	*Name*
1	Environmental chamber
2	Drum test bench
3	High precision data acquisition equipment
4	CAN card
5	Current clamp
6	High voltage testing line
7	Flow sensor
8	Pressure sensor
9	Type K thermocouple
10	Computer

3.3. Test Conditions and Data Collection Points

Test condition basis "China automotive test cycle--Part 2: Heavy-duty commercial vehicles" execute, It is applicable to commercial vehicles with a maximum design total mass greater than 3500kg.

This operating condition is designed with dedicated cycles for different vehicle types to ensure targeted and representative testing, including: trucks: CHTC-LT (maximum design gross vehicle weight ≤ 5500kg) or CHTC-HT (GVW>5500kg); Ordinary Bus: CHTC-C; Semi trailer tractor: CHTC-TT; Self dumping truck: CHTC-D; City Bus: CHTC-B. The test vehicle model for this test is a pure electric dump truck, so the CHTC-D is used as the test condition for the overall vehicle energy flow test.

The speed curve of CHTC-D operating condition is divided into two main speed ranges: low speed and high speed, with a total duration of 1300 seconds. The low-speed section simulates low-speed driving conditions around cities or construction sites, while the high-speed section corresponds to the road transportation phase. The overall curve exhibits a stable operating characteristic with minimal acceleration and deceleration behavior, which is consistent with the actual driving habits of heavy commercial vehicles. The total mileage is 8.37km, with a maximum speed of 71.4km/h and an average operating speed of 29.07km/h. The operating condition curve is shown in Figure 1.

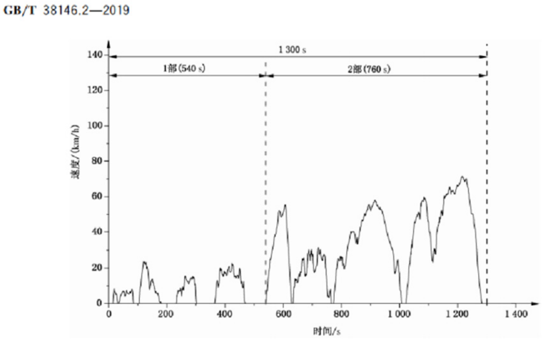

Figure 1. CHTC-D operating condition curve

The statistical characteristics of the CHTC-D operating condition curve are shown in Table 3.

Table 3. Statistical characteristics of CHTC-D operating condition curve

Feature	*Totality*	*Part 1*	*Part 2*
Running time/s	1300	540	760
Mileage /km	8.37	0.98	7.40
Maximum speed/(km/h)	71.40	23.70	71.40
Maximum acceleration (m/s^2)	1.24	0.75	1.24
Maximum deceleration/(m/s^2)	-1.08	-1.08	-1.03
Average speed/(km/h)	23.19	6.52	35.03
Operating average speed/(km/h)	29.07	11.04	37.13
Average acceleration during acceleration phase/(m/s^2)	0.36	0.36	0.36
Average deceleration during deceleration phase (m/s^2)	-0.40	-0.34	-0.43
Relative positive acceleration/(m/s^2)	0.11	0.10	0.11
Acceleration ratio/%	24.00	14.81	30.39
Deceleration ratio/%	22.08	16.48	26.05
Uniform speed ratio/%	33.69	27.78	37.89
Idle ratio/%	20.23	40.93	5.66

In order to comprehensively analyze the energy flow situation of the entire vehicle, this experiment covers the drive system, auxiliary system, and thermal management system. The power signals of key components of each system are collected, and the flow rate, pressure, temperature, and CAN signals are also collected to provide comprehensive data support for the verification and optimization of energy management strategies. The main measurement points for signal collection are shown in Table 4. At the same time, in order to compare the impact of ambient temperature on vehicle energy consumption, this experiment conducted energy flow tests at two temperatures: room temperature and low temperature. The test method and steps shall be carried out in accordance with GB/T 18386.2-2022 "Test Methods for Energy Consumption and Range of Electric Vehicles Part 2: Heavy Commercial Vehicles".

Table 4. Energy flow test signal acquisition point

Number	*Name*
1	Power battery output
2	Drive motor controller input
3	Drive motor controller output (UVW)
4	Steering oil pump motor controller input
5	Air pump motor controller input
6	Air pump motor controller output (UVW)
7	DCDC input
8	DCDC output
9	Battery output
10	Air conditioning compressor input
11	Water cooling unit input
12	Pump input
13	Fan input

3.4. Test Data and Analysis

The energy flow data of each key component at room temperature (23 °C) and low temperature (-15 °C) are shown in Table 5. Among them, the electricity consumption per kilometer (calculated based on discharge capacity) is the total discharge capacity of the power battery divided by the total operating mileage.

Table 5. Statistics of Operating Condition Data

Operating mode	*Normal atmospheric temperature*	*Low atmospheric temperature*
Battery discharge capacity kWh	208.3	210.2
Motor power consumption kWh	168.7	165.4
24V power consumption kWh	7.9	4.0
Power consumption of water-cooled unit kWh	8.5	0.4
Air conditioning power consumption kWh	3.4	0
Battery PTC power consumption kWh	0	9.2
Chassis PTC power consumption kWh	0	10.2
Braking energy recovery rate %	25.3	22.5
Discharge DCDC efficiency %	96.4	96.1
Electricity consumption per kilometer (discharge calculation) kWh/km	1.8	2.1

From the power consumption data per kilometer in Table 5, it can be seen that the vehicle's energy consumption is higher in low-temperature conditions compared to high-temperature conditions.

Under normal temperature conditions, the energy consumption of each key component is shown in Figure 2.

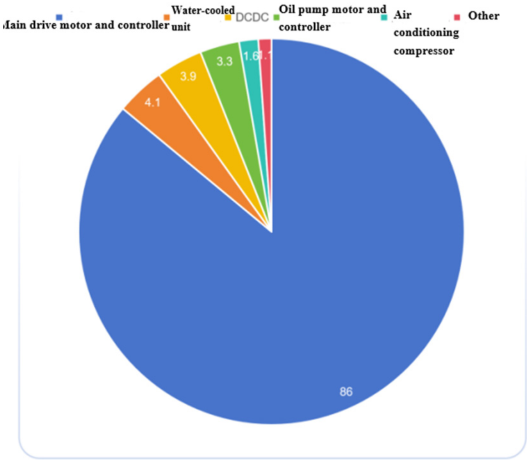

Figure 2. Proportion of component energy consumption under normal temperature conditions (%)

From Figure 2, it can be seen that the energy consumption of the main drive motor and controller under normal temperature conditions accounts for the largest proportion, reaching 86%. The energy consumption of the water-cooled unit and low-voltage electrical components is not significantly different, accounting for about 4%. That is to say, the drive system is the assembly with the largest energy consumption of the entire vehicle.

Under low-temperature conditions, the energy consumption of each key component is shown in Figure 3.

From Figure 3, it can be seen that the energy consumption of the main drive motor and controller under low-temperature conditions accounts for the largest proportion, reaching over 80%, followed by the chassis PTC and battery PTC, accounting for 4.8% and 4.4% respectively. That is to say, the assembly with the highest energy consumption of the entire vehicle under low-temperature conditions is also the drive system, but its proportion has decreased compared to normal temperature conditions.

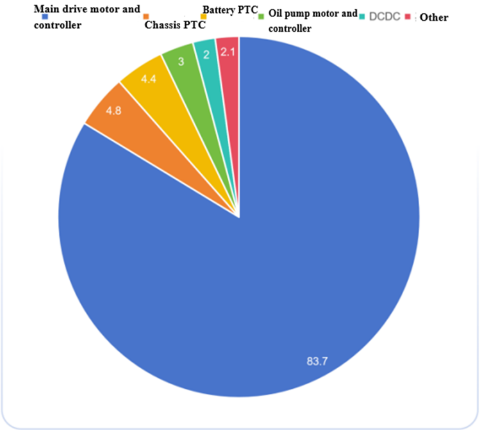

Figure 3. Proportion of energy consumption of components under low-temperature working conditions (%)

The comparison of energy consumption in different SOC segments of the vehicle under different ambient temperatures is shown in Figure 4.

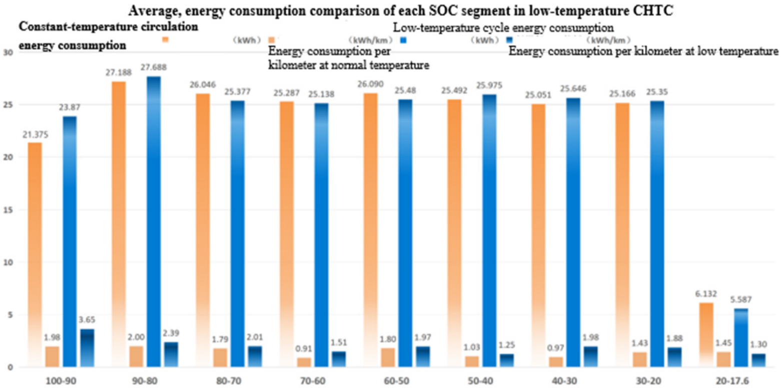

Figure 4. Comparison of energy consumption in different SOC segments of vehicles at room temperature and low temperature

From Figure 4, it can be seen that the unit energy consumption per kilometer under normal and low temperature conditions is significantly higher in the SOC>80% operating range than in the SOC<80% operating range, which is related to the energy recovery strategy and the working status of thermal management system components.

In addition, through data analysis, the vehicle mass and acceleration parameters remain consistent under normal and low temperature conditions, but the average power of the drive system differs significantly in the acceleration stage, indicating that achieving the same acceleration under low temperature conditions requires overcoming greater resistance. The main reason is that the cooling oil required for low temperature and normal temperature conditions is different, resulting in an increase in the average power of the drive system.

Based on the above, the reasons for high energy consumption in the SOC>80% operating range at room temperature and low temperature are as follows:

(1) The power of the driving motor is too high

- At room temperature, the driving motor power during the SOC>80% stage is 3.51% higher than that during the SOC<80% stage;

- Under low temperature conditions, the driving motor power during the SOC>80% stage is 8.6% higher than that during the SOC<80% stage;

(2) The proportion of braking energy recovery decreases

- At room temperature, the braking energy recovery ratio during the SOC>80% stage is 9.88% lower than that during the SOC<80% stage;
- In low-temperature environments, the braking energy recovery ratio during the SOC>80% stage is 29.24% lower than that during the SOC<80% stage;

(3) The working states of thermal management systems such as water-cooled units, air conditioning, battery PTC, chassis PTC, etc. are different, especially during the SOC>90% working condition stage, which is more obvious.

4. Conclusion

This article starts with the significance of energy flow analysis, testing methods, selection of testing points, testing equipment, etc., and uses a practical case to describe in detail the energy flow testing and analysis process of a certain pure electric heavy-duty truck. The obtained data can help product developers intuitively identify where energy consumption occurs; And through the comparison of two temperature conditions, the direction of energy management optimization has been preliminarily identified. Further simulation and real vehicle verification of the optimization plan are needed to ensure its feasibility.

Commercial vehicles are currently the main source of carbon emissions in the automotive industry, and their electrification transformation is crucial for reducing emissions. To promote this transformation, the key lies in reducing the operating costs of electric commercial vehicles, and energy consumption control is its core breakthrough point. Conducting energy flow testing and analysis, and implementing corresponding energy optimization, is an effective solution to this issue.

China's new energy vehicle industry has entered an important period of development opportunities, and it is necessary to strengthen the research and development of key core technologies, accelerate the deep integration of scientific and technological innovation and industrial innovation, consolidate and expand advantages with high-level technological self-reliance, and create a global innovation source for new energy vehicles.

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