Design and Simulation Analysis of Hybrid Power System for Mining Truck

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Abstract

Hybrid mining trucks can not only reduce pollutant emissions, and improve fuel economy, but also improve the range and transportation efficiency of vehicles. This paper designs the power system structure of a mining truck that matches the main power components such as drive motor, transmission speed, and so on, and simulates the relevant requirements of the target vehicle's power performance by using simulation software. Simulation results show that the maximum speed of the target vehicle reaches 42 km/h, the maximum acceleration exceeds 2 m/s, and the maximum climb degree is greater than 28° . The simulation results show that the selected series dual-drive motor meets the power performance of the target vehicle and verifies the rationality of the mining truck hybrid power system design.

Keywords

Mining Truck; Hybrid Power; Parameter Matching; MATLAB Simulation.

1. Introduction

Traditional mining trucks have large emissions and serious environmental pollution, so the development of new energy mining trucks is an inevitable development trend [1]. As all countries pay more and more attention to environmental protection issues, new energy vehicles are vigorously advocated and developing in all countries around the world, and hybrid models are also developing rapidly. Hybrid power and pure electric technology are gradually maturing, and countries around the world have gradually launched several new energy power models and have achieved a good market reputation. Hybrid technology has greatly reduced carbon emissions from vehicles and to ensure the range of the vehicle, is a new power car worth vigorously developing in the new energy era [2].

Mineral transportation is one of the main production links of open-pit mining, truck is the main transport vehicle of mining transportation. The survey shows that the investment cost of mining and transportation systems accounts for about 40%~60% of the total investment cost of mines, and the transportation cost of some open-pit mines is the proportion of the total cost of open-pit mine production has even exceeded 60% [3]. Domestic mineral transport trucks mainly use a diesel engine as the power, high fuel consumption, and large emissions, causing serious pollution to the surrounding environment [4]. Due to the large load, poor driving road conditions, and the road conditions of many steep slopes and turns, the power requirement of the mining truck is high[5]. The use of a hybrid power system, not only can greatly improve the fuel economy of mining trucks, but also can ensure the long endurance of mining trucks, and the power structure design and parameter matching of the hybrid system directly determine the power performance of vehicles is an important link in the development of new energy vehicles and has a significant impact on the performance of the whole vehicle [6].

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2. Power Structure Design for Hybrid Mine Truck

According to the technical indicators of power performance and economy of some type of mining truck, the whole vehicle performance parameters of the target vehicle are listed in Table 1. The design and matching of power parameters will be based on the listed parameters and meet the performance requirements in Table 1.

Table 1. Three Scheme comparing

Main Parameter	Unit	Numeric Value
curb weight	Kg	36000
Rated load	Kg	75000
Car bridge load	t	35+43+43
maximum speed	km/h	40
maximum gradability	%	28
minimum turning radius	m	11
Minimum ground clearance	mm	410
tire	/	16.00R25

Due to the large load weight of the target track, the power demand for the drive motor varies greatly at empty and full load [7]. Using a single high-power motor to drive, it cannot guarantee that the drive motor is still running in the power-efficient area, resulting in power loss, and the single motor diameter is large, which will reduce the ground clearance of the vehicle [8]. Therefore, this paper uses double drive motor series drive as the power source of mining trucks. The hybrid model of the mining truck adopts the series mode, namely, the engine, generator, and drive motor form a series hybrid power system. The engine operates in the speed range of the maximum thermal efficiency and only drives the generator to generate electricity, conveying electricity directly to the high-voltage bus. The driving force is provided by the tandem dual drive motor through the transmission and transmission system, ensuring that both the engine and drive motor operate in the maximum efficiency range and improving the fuel economy of the hybrid system [9], The principle of the hybrid dynamic structure is shown in Fig. 1.

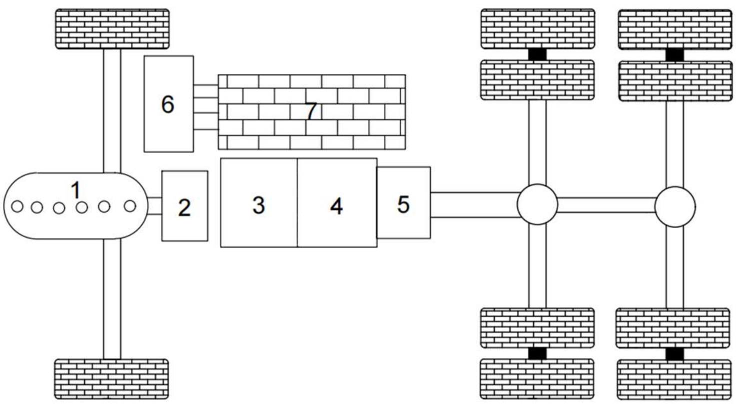

Fig. 1 Schematic diagram of hybrid power system for mining trucks

1 Engine; 2 generator; 3 left drive motor; 4 right drive motor; 5 transmission; 6 distribution box; 7 power battery pack

3. Matching and Selection of the Drive Motor Parameters based on the Target Vehicle

3.1 Vehicle Power Calculation

The target vehicle converts the electricity output from the power battery into mechanical energy to overcome the rolling, air, acceleration and climbing resistance that occurs during driving. The selection and matching performance of the power transmission system determines the power performance and economy of the target vehicle. The power drive system of the target vehicle mainly consists of an electric drive system and a speed device, in which the electric drive system includes a drive motor, power battery, and motor controller, while the speed device uses the same gearbox and main reducer of the same type of fuel vehicle.

From the power balance equation of the vehicle, the vehicle power under any operating condition for [10]:

$$P=\frac{v}{3600\eta_t}\left(mgf\cos\alpha+mgf\sin\alpha+\frac{C_D A v^2}{21.15}+\frac{\delta m}{3.6}\frac{du}{dt}\right) \tag{1}$$

P is the required power of the vehicle when driving (kW); v is the driving speed (km/h); η_t is the efficiency of the transmission system; m is the curb weight of the vehicle (kg); g is the acceleration of gravity (g=9.8 kg·m/s2); f is the rolling resistance coefficient; α is the slope angle (°); C_D is the wind resistance coefficient; A is the windward area of the vehicle (m2); δ is the conversion coefficient of vehicle rotating mass; du/dt is the driving acceleration (m/s2).

The rated power and peak power of the driving motor are two of all the parameters of the driving motor that have a great impact on the performance. Reasonable selection of these two parameters determines the performance of the hybrid mining truck. Under normal circumstances, the greater the power of the selected drive motor, the better the maximum climbing degree and acceleration performance of the mining truck, but the volume and mass of the motor are larger, and the motor can not remain in the efficient area for a long time, and its power factor and efficiency will be reduced [11], Reducing the energy utilization rate of electric vehicles, reducing their driving range. If the power selection of the drive motor is too small, the power performance index of the vehicle will not meet the design requirements, and the drive motor will be working in the overload state for a long time, resulting in its life being seriously shortened.

The peak power of the vehicle is mainly based on the maximum speed, maximum climbing degree, acceleration capacity, and other related technical requirements, vehicle quality, air resistance coefficient, and vehicle transmission efficiency [12], relevant parameters determine that the peak power of the motor must meet the following requirements: power demand for maximum speed, power demand for a maximum climbing degree, and power demand for acceleration performance. Because the mass of the mine card at no load and full load varies greatly, the power required at no load and full load varies greatly, and the maximum power at no load cannot meet the power demand at full load, so the maximum power should be calculated according to the working condition at full load.

(1) Maximum power (Pmax1) as determined according to the maximum vehicle speed:

$$P_{\max 1}=\frac{v_{\max}}{3600\eta_t}\left(mgf+\frac{C_D A v_{\max}^2}{21.5}\right) \tag{2}$$

(2) Maximum power (Pmax2) determined according to the maximum climbing degree of the mine card:

$$P_{\max 2} = \frac{v_i}{3600\eta_t}\left(mgf\cos\alpha_{\max} + mg\sin\alpha_{\max} + \frac{C_D A v_i^2}{21.5}\right) \tag{3}$$

(3) The maximum power (Pmax3) is determined according to the acceleration performance of the mining card:

$$P_{\max 3} = \frac{v}{3600\eta_t}\left(mgf + \frac{C_D A v_m^2}{21.5} + \frac{\delta m}{3.6}\frac{dv}{dt}\right) \tag{4}$$

v is the speed at the later stage of acceleration; dv/dt is the acceleration at the later stage of acceleration; v_m is the final speed; The acceleration is calculated according to the acceleration value of the same type of fuel mining truck. The maximum power determined according to the acceleration performance is measured on a flat road. At this time, the slope is 0, so the slope resistance is not calculated.

According to the calculated peak power requirements, the motor peak power must meet the maximum speed, maximum scalability, and acceleration performance [13], approach:

$$P_{peak} \geqslant \max(P_{\max 1}, P_{\max 2}, P_{\max 3}) \tag{5}$$

According to the calculation, the drive motor selects a three-phase AC permanent magnet synchronous motor with a peak power of 520 kW. The peak power of the double motors in series is 1040 kW, which can meet the power demand of the mini card and has power redundancy to ensure the stable operation of the motor. The specific parameters of the selected motor are shown in Table 2.

Table 2. Parameters table of the single drive motor

Parameter	Numeric Value	Parameter	Numeric Value
Rated voltage (VDC)	540	Peak power (kW)	520
Rated rotational speed (r/min)	1800	Peak Torque (N/m)	2600
Motor continuous output power (kW)	350	Maximum rotational speed (r/min)	3500

The transmission system of the target vehicle adopts the same eight-gear manual transmission and main reducer of the same type of fuel truck. The fuel truck of the same type has undergone a lot of practical work tests to meet the performance needs of the vehicle. The maximum transmission ratio of the selected transmission is 6.73, and the main reducer drive ratio is 16.086.

3.2 Motor torque matching

The external characteristic curve of the motor is shown in Fig. 2. The external characteristics of the motor are divided into constant torque area and constant power area.

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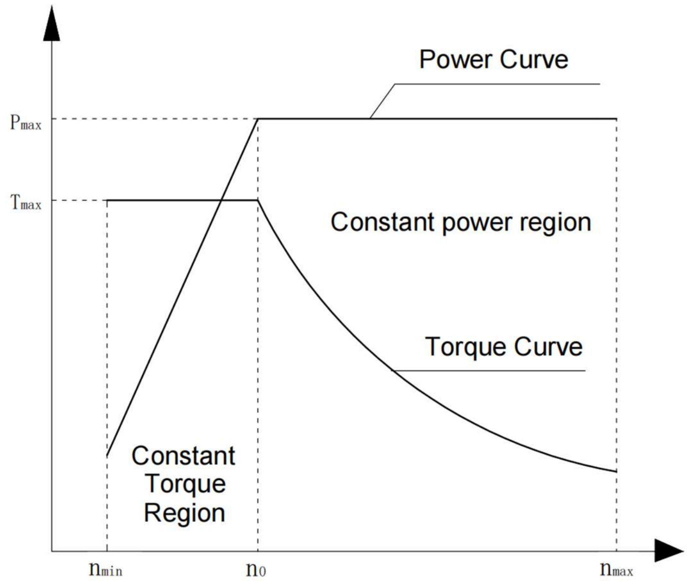

Fig. 2 External characteristic curve of the motor

The motor selects two three-phase AC permanent magnet synchronous motors of the same model. The constant torque of the motor used is 1650 N/m. The speed and torque sampling of the motor in the constant power area are shown in Table 3.

Table 3. Table of speed and torque in constant power zone of the drive motor

Speed (r/min)	torque (N/m)	Speed (r/min)	Torque (N·m)
1800	1650	2300	1405
1900	1587	2400	1380
2000	1528	2500	1357

According to the speed and torque of the motor external characteristics of constant power area, using MATLAB curve fitting toolbox "Curve Fitting Tool" order 2 polynomial coefficient to fit the motor in the constant power area of the secondary polynomial fitting curve as shown in Fig. 3, the curve trend and the motor external characteristic curve of constant power, get the motor external characteristic of constant power area, the relationship between motor torque and speed is:

$$T_e = 3.223 \times 10^{-4} n^2 - 1.805n + 3853 \tag{6}$$

T_e is the torque in the constant power region of the motor; n is the motor speed; T_m is the torque in the constant torque zone of the motor; The sum of squares of error (SSE) is 37.76; The complex correlation coefficient (R-square) is 0.9997; The root means square error (RMSE) is 0.5749. Therefore, the approximate relationship between the output torque and rotation speed of the motor can be expressed as:

$$T_e = \begin{cases} T_m & n \leq n_b \\ 3.223 \times 10^{-4} n^2 - 1.805n + 3853 & n > n_b \end{cases} \tag{7}$$

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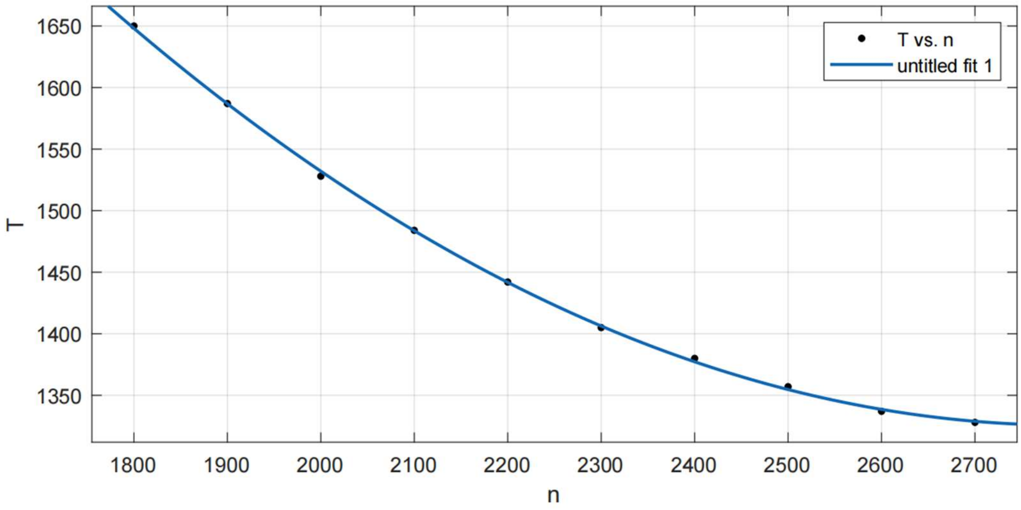

Fig. 3 A quadratic polynomial fitting graph of the constant power region

4. Simulation and Simulation Results of the Hybrid System

The torque and power of the selected motor parameters are simulated to verify whether the performance of the selected drive motor meets the performance requirements of the target vehicle. The rotation speed, power, and torque of the motor are taken as the power parameters of the simulation. According to the principle of vehicle dynamics, the rolling resistance, air resistance, acceleration resistance, and slope resistance of the vehicle are calculated. Combined with the transmission ratio of the gearbox and the main reducer, the driving force and the vehicle resistance, the acceleration performance, and the ramp degree are simulated. The simulation model is shown in Fig. 4.

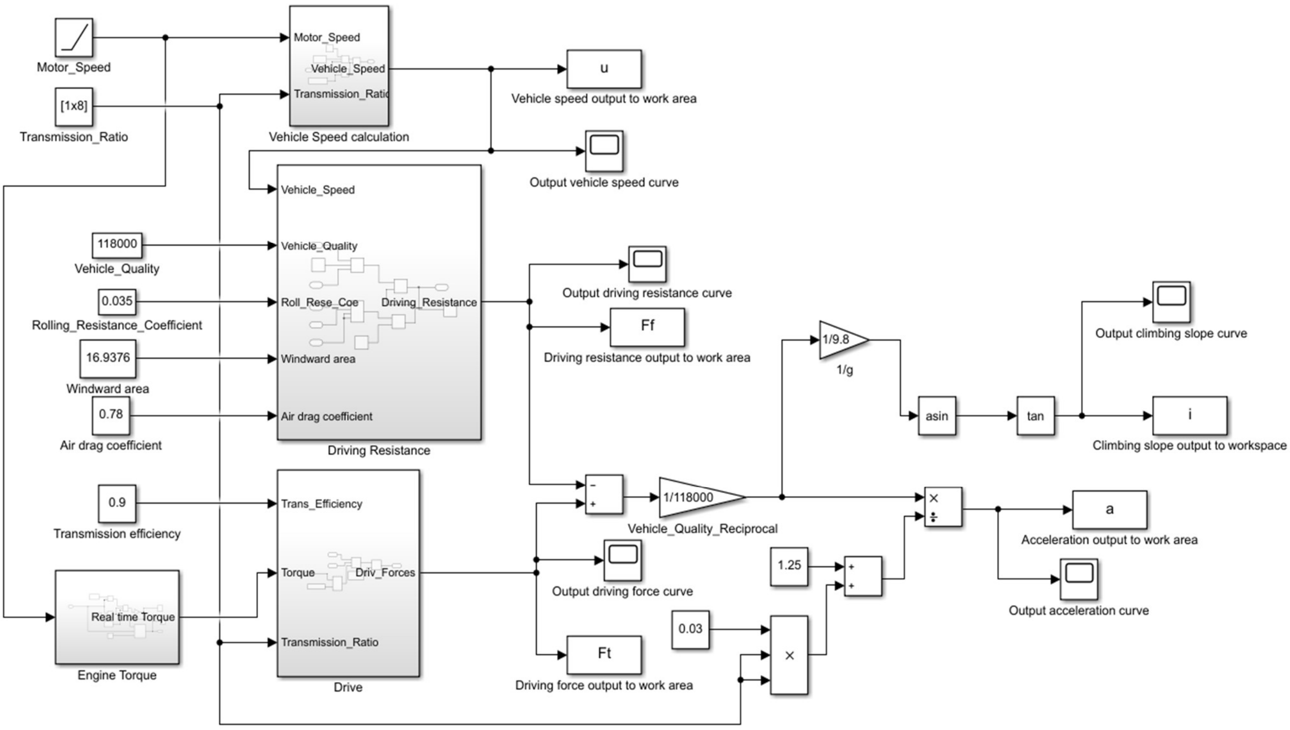

Fig. 4 Simulation model diagram of the dynamic performance of the hybrid ore card

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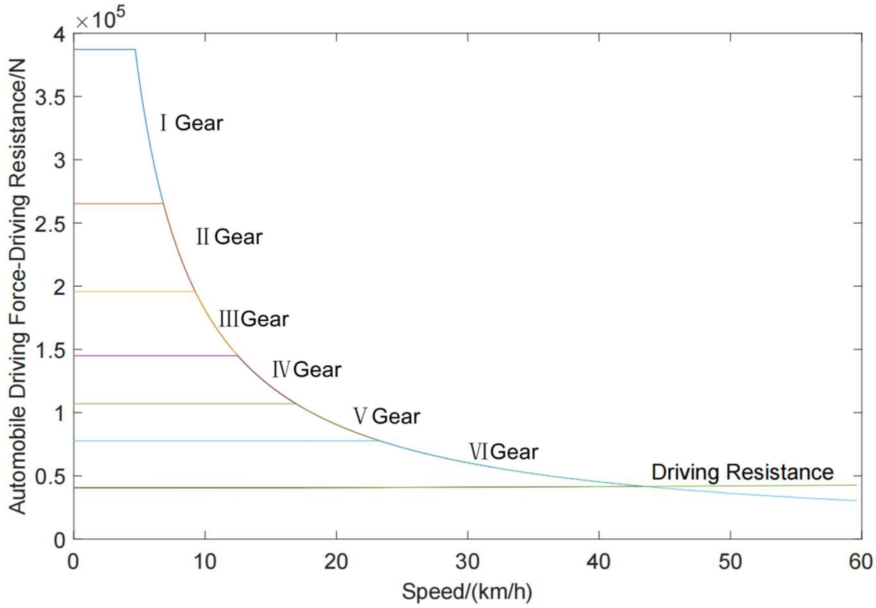

Fig. 5 Balance diagram of driving force and driving resistance for hybrid mining trucks

The simulation results of the driving force and driving resistance of the target vehicle are shown in Fig. 5. It can be seen from the balance diagram of the driving force and driving resistance that the maximum speed of the mine card at full load is about 43 km/h, and the maximum speed can be reached in the sixth gear, meeting the design target of the maximum speed of the target vehicle.

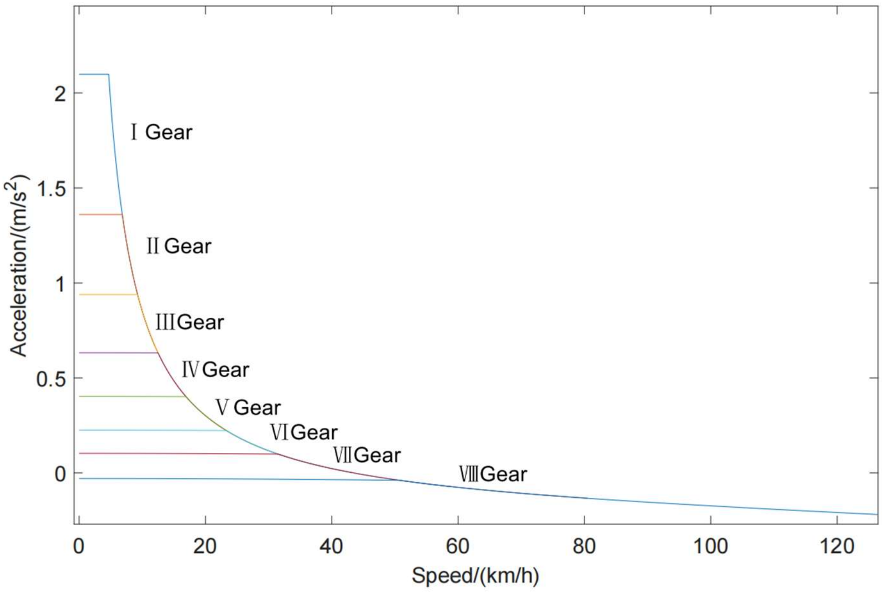

Fig. 6 Acceleration curve of my card at full load

According to the acceleration curve of the mine card at full load in Fig. 6, the maximum torque gear of the target vehicle is one gear, and the maximum acceleration of the mine card at full load is more than 2.1 m/s2. The acceleration in seven gears is still greater than zero, indicating that the maximum speed gear of the target vehicle at full load is seven gears, which meets the design requirements of the target parameters of the mini card.

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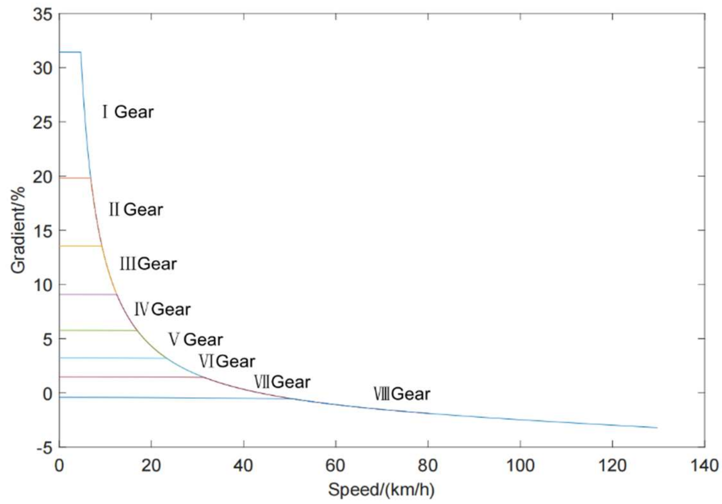

Fig. 7 Climbing degree curve at full load

According to Fig. 7 of the simulation results of the climbing degree at full load, the maximum climbing degree of the target vehicle in the first gear is 31°, which meets the design requirements that the maximum climbing degree of the target vehicle is 28°. The simulation results show that the torque and power of the selected motor meet the power performance design requirements of the target vehicle.

5. Conclusion

Based on the problems of large emissions and serious environmental pollution, the structure and parameter matching and selection of the main power components. MATLAB simulation software is used to simulate the power performance of the drive motor and transmission speed. The results show that the selected series double-drive motor meets the power performance of the target vehicle, and the maximum speed, maximum climbing degree, acceleration capacity, and driving range of the matched designed hybrid power system all meet the design requirements. The rationality of the hybrid system for mining trucks is verified.

Acknowledgments

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