Design Theory and Performance Analysis of Electric Tractor Drive System

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Abstract: **Based on the electric drive characteristic of electric tractor, the design theory and calculation method of electric system and mechanical system of electrical tractor were studied deeply. Established a design scheme of electric tractor drive system; The design theory and calculation formula of electric tractor drive system were put forward, and the parameters of the main components such as drive motor, transmission and power battery were obtained. Taking 25 horsepower electric tractor as the research object, the parameters of the main components of the driving system were designed, and the curve of the external characteristic of the driving motor, the velocity characteristic curve and the time and speed of the one charge continuous operation were plotted. The analysis showed that the dynamic performance and endurance of the vehicle could meet the requirement of operation. The driving force fully satisfied the demands of the electric tractor plough operation, and the continuous operating time of the power pack battery could meet the performance requirement of the continuous working 6h.**

Keywords: Driving system; Parameter design; Design theory ; Performance analysis

I. INTRODUCTION

Fossil energy tends to dry up, energy crisis and environmental pollution are becoming more and more obvious, and traditional fuel vehicles turning into new energy vehicles are inevitable. In recent years, both at home and abroad are advocating energy is saving emission reduction, green development, accelerate the transformation of agricultural machinery, *National agricultural mechanization Science and technology development "Twelve is Five" plan* pointed out that speeding up the transformation of agricultural development mode, will increase production and efficiency, resource is saving, environment is friendly agricultural mechanization technology as the development direction of agricultural machinery technology[1]. Other than that, *"National agricultural mechanization Science and technology development" Thirteen is Five "plan"* put forward, firmly establish long letter, coordination, green, open, shared development concept, take the environment is friendly agricultural modernization road [2]. The research and development of electric tractor can effectively alleviate the energy crisis, which is significant for the long is term development of agricultural machinery.

The driving system of electric tractor is the key to the performance of the vehicle, and it is the foundation of the whole vehicle layout and design. This paper presents the design theory and method of a small wheeled electric tractor drive system, analyzes the basic structure of electric tractor drive system, designs and presents a new type of electric tractor drive system for 25 HP Electric tractor chassis layout and vehicle design. The parameter design of driving motor, transmission, power battery and other main components in drive system provides the theoretical basis for further research and development of electric tractor drive system.

II. ANALYSIS OF DESIGN SCHEME OF DRIVING SYSTEM

At present, electric vehicle drive system mainly has motor is drive axle assembly type, motor is drive axle integral type and wheel motor drive type three kinds of arrangement form [3]。

And the Electric tractor drive system is similar to the automobile drive system, it is reasonable and reliable to use the mature technology of the automobile driving system. Figure 1 shows the design of the Electric Tractor Drive system program, mainly by the power battery, battery management system, drive motor, motor control system, drive system, such as driving wheel components. When electric tractors work, by manipulating the accelerator pedal and brake pedal, the driver sends the signal instruction to the whole vehicle management system, the whole vehicle management system adopts the control strategy, transmits the signal instruction to the battery management system and the motor control system, the drive motor transmits the power to the driving wheel by the mechanical connection, realizes the electric tractor coordinated control.
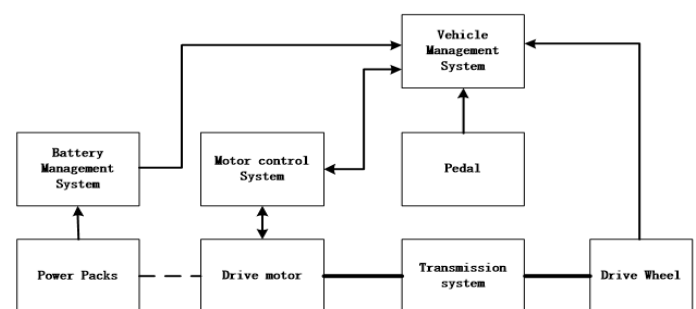

Figure 1 Driving system scheme of electric tractor

III. PARAMETER DESIGN OF MAIN PARTS OF DRIVING SYSTEM

Drive performance Calculation

In the working condition of the electric tractor, the driving force of the plough is maximum and the operating speed is about 4~6km/h. Due to the low speed of the electric tractor, the influence of air resistance can be neglected [4], the driving equilibrium equation of the electric tractor is defined as：

$$F_q = F_T + F_f \qquad (1)$$

In the formula, F_T is traction implements Resistance, N; F_f is rolling resistance, N.

The formula of F_T is:

$$F_T = Z b_l h_k k \qquad (2)$$

In the formula, Z is the number of plowshare; b_l is single plough width, cm; h_k is plough depth, cm; k is soil resistance, N/cm^2. The farm tool parameters are shown in table 1

As the tractor plough is more complex and the driving force is larger, it is usually defined that the rated driving force of the electric tractor is F_{TN}:

$$F_{TN} = (1.1 \sim 1.2) F_T \qquad (3)$$

The calculation formula of F_f is:

$$F_f = mgf \qquad (4)$$

In the formula, m is whole vehicle use quality, g is acceleration, take the value 9.8m/s^2; f is rolling resistance coefficient.

Table 1 Parameters of Plowshare

Number of plowshare	Plough depth /cm	Single Plough width /cm	Soil resistance /(N/cm^2)
3	18	20	5

Power calculation of driving motor

The driving power of electric tractor determines the size of the back is up power of the whole machine, which affects the performance of the whole machine. The power of electric tractor in plough work should meet:

$$P_q \geq \frac{F_{TN} V_L}{3600 \eta_q} \qquad (5)$$

In the formula, V_L is the maximum speed of plough; η_q is the traction efficiency of drive system.

The calculation formula of traction efficiency η_q:

$$\eta_q = \eta_{mc} \eta_m \eta_\delta \eta_f \qquad (6)$$

In the formula, η_{mc} is the efficiency of drive motor and control system; η_m is the efficiency of transmission system; η_m

is the slip efficiency; η_f is the rolling efficiency.

Calculation of maximum torque of driving motor

Torque satisfying formula of driving motor：

$$T_{max} = \frac{60000 P_{q\,max}}{2\pi n_e} \qquad (7)$$

In the formula, P_{qmax} is maximum driving power; n_e is Drive motor rated speed.

2.4 Design of fixed speed ratio reducer

The driving motor has "low is speed constant torque, high speed constant power" mechanical characteristics, the work of the motor college scope is larger, and the tractor working speed range is narrow, the tractor work without changing gears [5]. In this paper, a fixed speed ratio reducer is adopted and a transmission ratio is designed according to the tractor plow working condition:

$$i_g = 0.377 \frac{n_e R}{i V_L} \qquad (8)$$

In the formula, i_g is the ratio of the fixed speed ratio reducer; R is Drive wheel rolling radius, m; n_e is Drive motor rated speed, rpm; i is main reducer transmission ratio.

Design of Power battery pack

1) Energy calculation of power battery pack

According to the rated working time of the electric tractor, we can determine the total energy of the power pack which is theoretically consumed.：

$$W_{ess} = P_e \cdot T \qquad (9)$$

In the formula, P_e is rated power; T is rated working time; W_{ess} is theoretical total energy, kW·h.

2) Calculation of power Battery capacity

The total capacity of the battery pack is determined according to the theoretical total energy consumed by the power pack：

$$C_{ess} = \frac{1000 W_{ess}}{U_E} \qquad (10)$$

In the formula, U_E is the rated operating voltage of the power Battery, V; C_{ess} is The total capacity of the theory, A·h.

In fact, the power battery does not normally output all the power, you can use ξ_{SOC} (the effective discharge coefficient of the battery pack) to measure the actual output energy of the power pack. The actual total energy value of the battery W_R and the total capacity value C_R are calculated as:

$$\begin{cases} W_R = W_{ess} / \xi_{SOC} \\ C_R = C_{ess} / \xi_{SOC} \end{cases} \qquad (11)$$

3) Quality design of electric tractor

The actual output driving force of the drive motor is related to the maximum use quality of the tractor, and the maximum use quality of the electric tractor should make the designed tractor play the rated driving force under the condition that the slip rate does not exceed the specified value [6].

$$G_{s\,\max} \geq \frac{F_{TN}}{\varphi_\delta \lambda - f} \qquad (12)$$

In the formula, λ *is* the load distribution coefficient; φ_δ is the adhesion coefficient of allowable slip is rate δ; G_{smax} is The maximum use weight of electric tractor.

IV.   RESEARCH OBJECT DESIGN AND ANALYSIS

The main components of the Electric tractor drive system are designed and analyzed with the above formula by using the 25 HP Electric tractor which is being developed.

A.   Parameter design of main parts

Based on the above design theory formula, the design parameters of the main components of electric tractor drive system are calculated, and the performance index of the electric tractor is given, as shown in table 2.

Table 2 Design parameters and performance indicators of electric tractor

Main parts	Project	Parameter value
Vehicle	Maximum use quality /kg	2000
	Main deceleration ratio	8.6
	Rated operating time /h	6
	Rated traction /N	
	Maximum speed of plowing / （km/h）	7.5
	Maximum driving speed / （km/h）	30
Drive motor	Rated speed (maximum speed) / （r·min$^{is\,1}$）	3500（7500）
	Rated power (maximum power) /kW	20945)
	Rated torque (maximum torque) / （N·m）	54.6（190）
Transmission	Ratio	17
Power Packs	Rated voltage /V	320
	Total energy of the battery pack / （kW·h）	100
	Total capacity of battery pack / （A·h）	485

B.   Main performance analysis

The graph of main performance of electric tractor is drawn by MATLAB programming calculation. Fig. 2 shows the external characteristic curve of the driving motor.
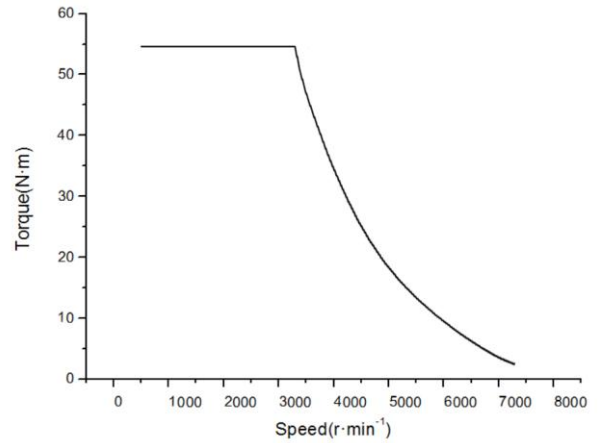

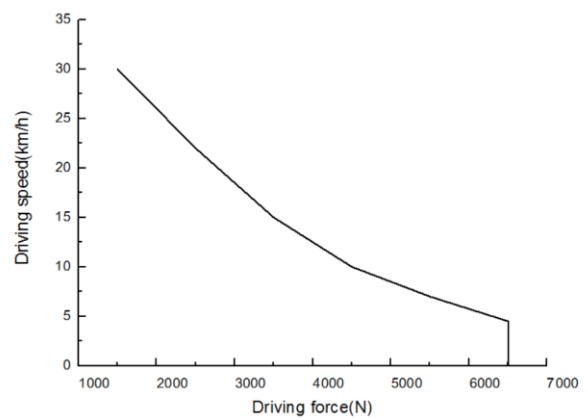Figure 2 External characteristic curve of driving motor

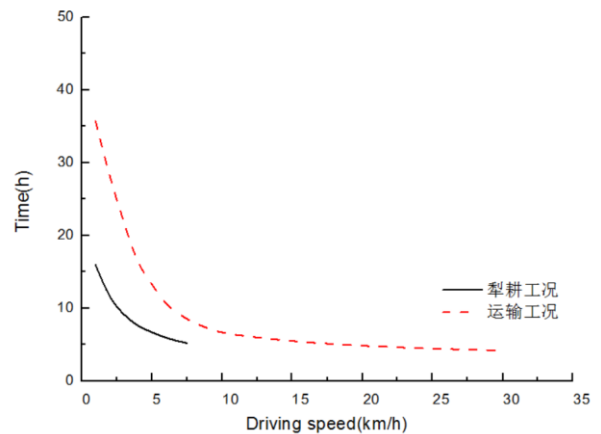Figure 3 The relation curve between driving force and traveling speed

Figure 4 The relation curve between the time and the traveling speed of one charge continuous operation

As shown in Fig. 3, the relationship between the driving force and the traveling speed when the driving force is 6500N (plough working condition), the traveling speed is 4.5km/h; When the driving force is 4500N (transport load is carrying condition), the driving speed is 10km/h; When the driving force is 1500N (tractor no is load condition), the driving speed is 30km/h.

As shown in Fig. 4, the relationship between the time of the charge and the speed of the operation, the working time of the electric tractor varies with the working condition and speed, and the driving speed is increased and the continuous operation time is shortened under the same working conditions. Under the same driving speed, the continuous working time varies with the working condition. When the driving speed is 5km/h, the continuous operation time of plough is up to 6.7h, the continuous operation time can be up to 13. 4h, all meet the design requirements.

V. CONCLUSION

Aiming at the wheeled small horsepower electric tractor, this paper presents a new design scheme of the Electric tractor drive system, simplifies the power transmission mode, makes the chassis layout more flexible and simple, puts forward the design theory and method of the driving system, and combines the case to design and calculate, completes the drive motor, the transmission, Parameter design and main performance analysis of main components such as Power pack. The analysis shows that the 5km/h of the Power battery is 6.7h to meet the preset 6h requirements.

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