Dynamic Performance Simulation Analysis of Electric Forklift Truck Based on ADVISOR

Li Zhang*
Department of Vehicle Engineering, Shandong Transport Vocational College, Weifang, China

*Corresponding author email: zhangli.0424@foxmail.com

Abstract. According to the power system selection and technical parameters of the lithium titanate electric forklift that have been matched, the ADVISOR simulation software modeled the parameters of the drive motor, lithium titanate battery, reducer and other major components of the system. The acceleration ability, climbing ability and energy consumption of lithium titanate-electric forklift are simulated, and its technical parameters are obtained, which provides a basis for testing the rationality of system parameter matching.

Keywords: Dynamic performance, simulation analysis, forklift, ADVISOR.

1. Introduction
ADVISOR is a vehicle dynamics simulation software developed by NREL based on Matlab software. It can simulate and analyze various aspects of the performance of common vehicles, including electric vehicles. Software has the following advantages [1]: (1) source code and open; (2) Forward and backward hybrid simulation; (3) Modular simulation model; (4) Compatible with a variety of programming languages; (5) Combined with a variety of software simulation. The software can be used to simulate more than just traditional cars.

Lithium titanate electric forklift has the advantages of fast charging speed and long cycle life, which is of great significance in the field of pure electric forklift. In view of the particularity of the lithium titanate electric forklift, the power performance of the lithium titanate electric forklift was simulated by ADVISOR software to verify the rationality of the early power system design and selection. The simulation process is mainly divided into three steps [2-5].

(1) Build the forklift dynamics configuration. According to the design and selection parameters of the power system components of lithium titanate electric forklift truck, the dynamics models were constructed respectively.

(2) Set the simulation operation parameters. After completing the dynamic model of each part of the vehicle, the driving conditions and initial conditions of the forklift truck were set.

(3) Output simulation results. After completing the setting of technical parameters, the power performance curves of lithium titanate forklift truck are generated respectively, including: climbing capacity, mileage, etc.

2. Construction of Lithium Titanate Electric Forklift Dynamics Model
Power performance is an important index to evaluate the performance of a forklift. The power performance parameters of lithium titanate electric forklift determine its working efficiency. According to the selection and parameters of the main power system components in the matching design of the power system of the forklift truck, the vehicle dynamics model of the lithium titanate electric forklift truck was established by referring to the process and method of power system model
construction in ADVISOR software. Key components driving motor, lithium titanate battery, reducer model construction is very important.

2.1 Drive Motor Model Construction
The parameter model of the moving motor of lithium titanate electric forklift truck is established according to the technical parameters of the driving motor after the vehicle selection and design. Motor parameters include rated voltage, rated speed, power curve, etc. Based on the heat exchange, operation characteristics and other performance indexes of the driving motor tested by experiments, the model is constructed. The specific parameters of the driving motor are shown in Table 1. Edit and input the corresponding data of each module shown in Table 1, define the characteristics, and get the walking motor ADVISOR model.

2.2 Lithium Titanate Battery Model
Lithium titanate battery is different from other lithium batteries. It has the characteristics of fast charging and long cycle life, which leads to the technical parameters different from the commonly used lithium iron phosphate battery and lead-acid battery.

| number | variable                | parameter     |
|--------|-------------------------|---------------|
| 1      | Speed(r/min)            | 0/700/1500/2200/2800 |
| 2      | Torque(N·m)             | 0/50/90/130/180 |
| 3      | Min voltage(V)          | 48            |
| 4      | Max current(A)          | 330           |
| 5      | Total mass(kg)          | 50            |

Through the test of lithium titanate battery, the current, voltage and State of Charge (SOC) of the battery during Charge and discharge are obtained. SOC are the ratio of the remaining capacity of the battery to the capacity of the fully charged State. The value range is 0~1, and when SOC=0, the battery is fully discharged. When SOC=1, it means that the battery is fully charged. The power limit, open circuit voltage, battery heat dissipation, calculation current and SOC algorithm required by the battery in the lithium titanate electric forklift truck are analyzed to determine the parameters required for model construction. According to the battery pack model parameters in Table 2, the battery model construction method in ADVISOR simulation software was applied to establish the parametric model of the power battery of lithium titanate electric forklift truck based on Matlab software.

| number | variable              | parameter     |
|--------|-----------------------|---------------|
| 1      | Battery capacity(A·h) | 98/98/98      |
| 2      | Battery number        | 32            |
| 3      | Single cell voltage(V)| 1.6-2.8       |
| 4      | The battery weight(kg)| 13            |

2.3 Reducer Model
The basic performance parameters of the gearbox are obtained by testing the mechanical properties of the gearbox. The simulation test of straight and ramp conditions does not involve the performance of differential speed change, but mainly tests the transmission efficiency and the performance of torque increase and decrease. The performance parameters obtained after testing are shown in Table 3. According to the model parameters of the gearbox in Table 3, the battery model construction method in ADVISOR simulation software was applied to establish the parameterized model of the gearbox of lithium titanate electric forklift truck based on Matlab software.
Table 3. The model parameters of the gearbox.

| number | variable               | parameter |
|--------|------------------------|-----------|
| 1      | Gearbox transmission   | 21.5      |
|        | ratio                  |           |
| 2      | Total weight of reducer| 16.5      |
|        | /kg                    |           |

2.4 Other Control and Accessory Models

By referring to the process and method of ADVISOR simulation software, the parameter model construction of other components of lithium titanate electric forklift truck was completed [6-8].

(1) Forklift driving model. The driving model of lithium titanate electric forklift truck is built. In the software model, the input terminals ① and ② are the output outlets of decelerating torque and speed, and the output outlets of mechanical braking force. Combined with the weight of the whole machine, tire efficiency, rolling coefficient and moment of inertia and other factors, the actual acceleration of lithium titanate forklift truck was obtained, and its displacement and speed were calculated by formula.

(2) Forklift control model. The control model of lithium titanate electric forklift truck was constructed. In the software model, the input end ① is the target speed of the forklift truck, ② is the throttle data; ③ is the brake data, and the output terminal ① is the speed and torque required by the driving motor; ② is the data of its braking force. The calculation module is for the required forklift braking force, acceleration distribution, motor power, power feedback, etc.

(3) Driver model. In ADVISOR, the driver model is built based on the fuzzy PID control theory. The output is the accelerator or brake pedal, and the input is the required value of the speed. The driving condition of lithium titanate forklift truck is used to simulate the operation of the driver, so the simulation parameter flow is consistent with the actual operating condition.

2.5 Vehicle Parameter Model

In conclusion, this paper constructs the ADVISOR parameterized model of the lithium titanate electric forklift truck. The parameter model of lithium titanate electric forklift truck includes several sub-module models, The module model of transmission system includes the data of torque and moment of inertia. The data of the lithium titanate battery model includes temperature, SOC, battery resistance, voltage and thermal parameters. The driving motor model includes power, torque and other parameters. Axle and wheel are the data of speed and traction required in simulation. These parameters are defined by the type of the MATLAB software file. Finally lithium titanate electric forklift truck load parameters is added. Such as dashboard, lights and other accessories energy consumption data.

3. Simulation of Power Performance of Lithium Titanate Electric Forklift Truck

The acceleration ability and climbing ability of lithium titanate electric forklift are the main indicators of its dynamic performance [9-10], and its economic performance is also an important performance index. In this paper, The dynamic performance is simulated from the above three aspects. According to the design requirements, the dynamic performance should meet the following indexes: the acceleration time from 0 km/h to maximum speed is less than 12 s; Minimum climbing slope > 14%; Single continuous working time > 3.5h.

3.1 Simulation of Acceleration Capability

The acceleration capability of the lithium titanate electric forklift will be simulated by the acceleration performance test module in ADVISOR simulation software. First, the SOC value of the maximum current discharge in the module is set to 1, and the time required for the speed of the electric forklift from 0 km/h to the maximum speed of 18 km/h is calculated by simulation. First, the unit is converted and matched with the software. After parameter adjustment, the simulation program is run to calculate the time change curve required by the forklift to accelerate from 0 speed to maximum speed, as shown in Figure 1:
Figure 1. Battery discharge simulation results.
From the simulation results, it can be obtained that the distance of lithium titanate electric forklift accelerated to the maximum speed is 12 m. The maximum speed of 18.2 km/h was reached in 8.7s. With the output of power, the acceleration of lithium titanate electric forklift gradually decreases, while the speed increases. According to the SOC simulation curve of lithium titanate battery, the SOC value changes little during the acceleration process, and only decreases by 0.007 during the whole acceleration process. According to the simulated current curve, the lithium titanate electric forklift requires a large torque in the starting process, and the battery output current rises rapidly at first, and then the current eases after the startup. After that, due to the stable operation of the forklift, the current gradually rises and finally reaches the maximum current of 382A.

In the normal operation condition of lithium titanate electric forklift, the driving motor is not always running in the maximum current condition. Therefore, in order to ensure the thermal stability and safety of the motor, the discharge rate of the battery should be appropriately reduced. It is assumed that the discharge ratio is set to 0.6c and the time required for simulation calculation is 8.2s. The test results of lithium titanate battery SOC are basically the same as those in 1C condition. To meet the design requirements of forklift trucks, so as to ensure safety and reliability, the battery discharge current is set to 0.6C.

3.2 Simulation of Climbing Ability
According to the operating conditions of lithium titanate electric forklift, it should meet the requirements of normal climbing capacity: minimum climbing slope > 14%. In the ADVISOR, the climbing speed was set to 5.1 km/h, the climbing time was set to 15 s, and the SOC value was set to 0.5. The corresponding test results of the simulation test are shown in Figure 3, all of which are > 14%, reaching the design goal. At the same time, through the above simulation test, the variation curve of each parameter in the 5.1km /h climbing process of forklift truck can also be obtained, as shown in Figure 2 and Figure 3.
According to SOC curve and battery current curve, SOC changes little and current is large. In order to ensure safety and climbing ability, the maximum discharge current of lithium titanate battery is reduced appropriately.

3.3 Simulation of Energy Consumption

The energy consumption simulation of lithium titanate battery needs to first establish the equivalent cycle condition, then carry out simulation calculation, and finally achieve the requirements of the working condition. Charging a single continuous working time > 3 h. Firstly, according to the dynamic performance, working conditions, operating environment and national standard test requirements of electric forklift, the equivalent cycle simulation of energy consumption for forklift truck was established in ADVISOR, as shown in Figure 6.

Through the analysis of the forklift working conditions and the calculation of the running speed, the equivalent cycle of the operation times is about 85 times (running for 3 h). After setting the parameters in ADVISOR software, the SOC and current change curves of the lithium titanate battery during the energy consumption process were obtained, and the travel distance curve of the forklift was also obtained, as shown in Figure 4 and Figure 5.
Figure 5. Battery current changes during the energy consumption cycle.

According to the above simulation curve, during the whole process of testing the electric forklift, the minimum power of the battery is not less than 15%, which meets the design technical requirements.

4. Conclusion

This paper introduces the ADVISOR simulation software and its test process, and builds the vehicle model in the software. In particular, the key components of driving motor, lithium titanate battery, reducer model construction are described in detail. Finally, the acceleration ability, climbing ability and energy consumption of lithium titanate-electric forklift are simulated to verify whether its performance indicators meet the design requirements.

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