Wuhan University of Technology

Graduation Design (Thesis)

The overall design of the unmanned electric logistics vehicle

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Abstract

In recent years, China's e-commerce logistics industry has developed rapidly, which has put forward higher requirements for distribution efficiency. In China's freight system, the proportion of express, rapid transportation and bulk freight markets is around 10%, 75% and 15%. In the freight market, the market share of express transport is the largest, but the decline in the market share of transport companies is the most serious. Although in recent years, with the development of artificial intelligence technology, the logistics industry has achieved a certain degree of progress in reducing costs and increasing efficiency. However, artificial intelligence is still in the technical reserve period, and it will take time to fully improve its performance. The use of universal delivery vehicles in production and life is still relatively traditional and inefficient. The entire industry is still waiting for new technological breakthroughs. From the current market demand, intelligent hardware such as unmanned vehicles and drones has become an effective tool for enterprises to promote their own development and improve logistics efficiency. Due to these reasons, the design of unmanned pure electric logistics vehicles needs to be carefully considered.

In this paper, electric unmanned logistics vehicle is studied. The overall selection and design optimization is carried out with Catia, Caxa, Python and other software and programming languages. Firstly, the overall design scheme of the unmanned electric vehicle is analyzed according to the design principles and related regulations and standards. The performance requirements of the automatic driving, is measured according to the environment sensing system, the decision planning system and the control execution system. Then the main technical parameters of the vehicle, including dimensions, quality and performance parameters are determined.

Finally, the structural types, characteristic parameters and arrangements of the main assemblies of the chassis are determined. Through the vehicle design calculation and analysis, it is ensured that the vehicle has reasonable power, driving range, braking performance, steering stability, driving comfort and passability.

Key Words：miniature pure electric logistics vehicle；driverless；overall design

Contents

Chapter 1 Introduction

1.1 The principle of electric vehicles

The pure electric vehicle is powered by vehicle power and driven by motor. It meets the requirements of road traffic and safety regulations, and generally uses high efficiency rechargeable battery as power source. Pure electric vehicles do not need to use internal combustion engines. Therefore, the electric motor of pure electric vehicles is equivalent to that of traditional automobiles. The battery is equivalent to the original fuel tank, and the electric energy is the secondary energy, which can come from many kinds of energy sources such as wind energy, water energy, heat energy, solar energy and so on[1].

1.2 Types of electric vehicle

Electric vehicle can be divided into two types, namely electric vehicles using pure batteries as power sources and electric vehicles with auxiliary power sources.

1.2.1 Electric vehicle with pure battery as power source

An electric vehicle using a single battery as a power source has only a battery pack, and its power and power transmission system is shown in Figure 1.1.

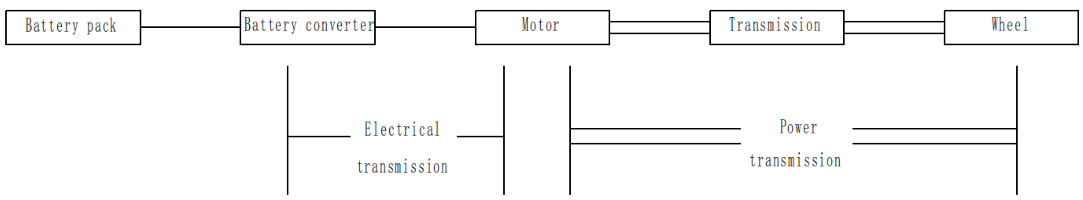

Figure 1.1 Electric vehicle with pure battery as power source

1.2.2 Electric vehicle with auxiliary power source

For an electric vehicle using a single battery as a power source, parameters such as the specific energy and power of the battery are low, and require high quality and large volume of the battery pack. However, in electric vehicle with auxiliary power sources, supercapacitors, generator sets, and solar energy are added to improve the starting performance and increase the driving range of the electric vehicles. The power and power transmission system of an electric vehicle equipped with an auxiliary power source is shown in Figure 1.2.

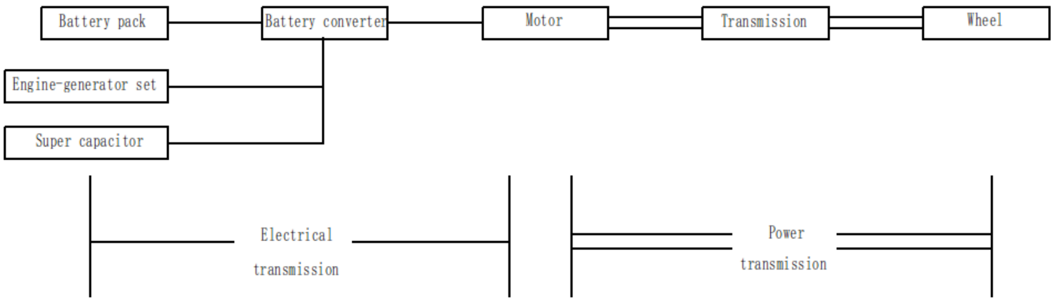

Figure 1.2 Electric vehicle with auxiliary power source

1.3 Electric vehicle structure

Fuel vehicle is mainly composed of engine, chassis, body and electricity. Compared with the fuel-fired vehicle, the structure of the pure electric vehicle mainly adds the electric drive control system, but cancels the engine. It consists of three parts: the electric drive main module, the vehicle power supply module and the auxiliary module[2].

1.4 Electric vehicle drive system layout

The essential part of an electric vehicle is the drive system, which determines the performance of the electric vehicle. The drive system arrangement of an electric vehicle depends on the way the motor drives the system. The common drive system layout is shown in Figure 1.3.

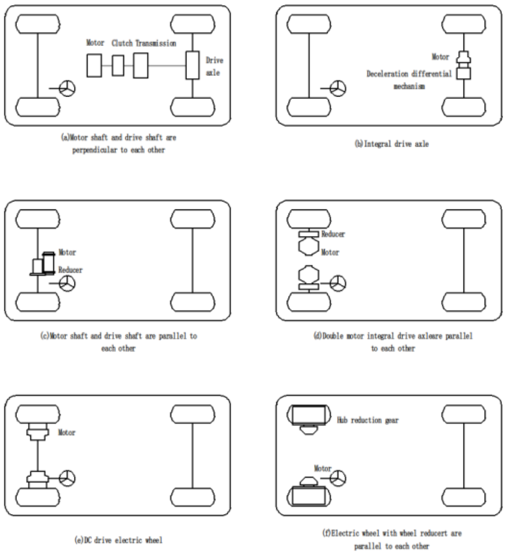

Fig. 1.3 Driving System Arrangement Scheme of Pure Electric Vehicle

1.4.1 Traditional drive mode

Figure 1-4 (a) shows the traditional car drive system, with a transmission and clutch, but the engine is replaced by an electric motor, which belongs to the modified electric vehicle. This arrangement can increase the starting torque of the electric vehicle and increase the backup power of the electric vehicle at a low speed.

1.4.2 Motor-drive axle combined drive mode

Figures 1-4(b) and 1-4(c) show that the clutch and the transmission are eliminated, but with a deceleration differential mechanism, the two wheels are made to rotate by one motor. The advantage is that the power train in the current car engine can continue to be used, requiring only one set of motors and inverters. This method has higher requirements on the motor starting torque and also requires a large backup power to ensure that there is enough power for the electric vehicle to start, climb, accelerate, and overtake.

1.4.3 Motor-drive axle integral drive mode

Figure 1-4(d) shows the motor and the differential conversion of the motor directly on the drive shaft. This type of transmission also has high requirements on the motor starting torque and backup power. At the same time, it requires not only high control precision of the control system, but also good reliability to ensure the electric vehicle travels Safe and stable.

1.4.4 Hub motor drive mode

Figure 1-4 (e) and Figure 1-4 (f) are similar to the arrangement of Figure 1-4 (d), the motor is directly mounted on the drive wheel, and the wheel is driven directly by the motor.

1.5 Electric car features

Compared with fuel vehicles, electric vehicles have the following characteristics.

(1) No pollution, low noise

An electric vehicle does not have any exhaust gas emission since it is without internal combustion engine. It is very beneficial to environmental protection and air quality. It has the reputation of “zero pollution”, and makes less noise compared with the internal combustion engine vehicles.

(2) High energy efficiency and diversification

The energy efficiency of electric vehicles has surpassed that of gasoline engines, especially when driving in the city, the car is stopped more frequently and the speed is not high. When the electric vehicle stops, it does not consume electricity. During the braking process, the electric motor can be automatically converted into a generator to realize the reuse of energy during braking deceleration.

On the other hand, the application of electric vehicles can effectively reduce the dependence on petroleum resources, and the limited oil can be used for more important applications. The electricity used to charge the battery can be derived from energy sources such as coal, natural gas, hydropower, nuclear power, solar energy, wind power, and tides. In addition, if the battery is charged at night, it can also reduce peak power consumption, which is beneficial to the grid to balance the load and reduce cost.

(3) Simple structure, easy to use and maintain

Electric vehicles are simpler in structure than internal combustion engines, with fewer running and transmission components, and less maintenance and repair work. When an AC induction motor is used, the motor is not maintained, and more importantly, the electric vehicle is easy to handle.

(4) High power consumption and short driving range

At present, electric vehicles are not as complete as those of internal combustion engine vehicles, especially the short life of power batteries and high cost. The battery has a small energy storage, the mileage after one charge is not ideal, and the price of the electric car is high. However, with the development of electric vehicle technology, the shortcomings of electric vehicles will be gradually solved.

1.6 Key technologies for electric vehicles

The development of electric vehicles must solve four key technologies: battery management technology, electric motor and control technology, vehicle control technology and vehicle lightweight technology[3].

1. Battery management technology

The battery is the source of power source for the electric vehicles, and it is also a key factor that has always restricted the development of electric vehicles. In order for electric vehicles to compete with fuel vehicles, a battery with high-efficiency, higher energy, higher specific power, longer service life and lower cost have to be developed. However, there is currently no battery that can meet the requirements of the popularity of electric vehicles.

The performance of the battery pack directly affects the acceleration performance of the vehicle, the driving range and the efficiency of braking energy recovery. The cost and cycle life of the battery directly affects the cost and reliability of the vehicle, and all parameters that affect battery performance must be optimized. The battery of an electric vehicle generates a large amount of heat during use, and the battery temperature affects the operation of the electrochemical system of the battery, cycle life and charge acceptability, power and energy, safety, and reliability. Therefore, in order to achieve the best performance and longevity, it is necessary to control the temperature of the battery pack within a certain range, reduce the uneven temperature distribution in the package to avoid the imbalance between the modules, thereby avoiding the battery performance degradation, and can eliminate related potential hazards[4].

2. Motor and control technology

The motor drive of an electric vehicle belongs to a special motor and is a key component of an electric vehicle. In order to make electric vehicles have good performance, the motor drive should have a wide speed range and high speed, large starting torque, small size, light weight, high efficiency, and dynamic braking energy and feedback performance. Electric motors used in electric vehicles are moving toward high power, high speed, high efficiency and miniaturization.

With the development of electric motors and drive systems, control systems tend to be intelligent and digital. Nonlinear intelligent control technologies such as variable structure control, fuzzy control, neural network, adaptive control, expert system, genetic algorithm, etc., are all applied to the motor control system of electric vehicles. Their application will make the system simple, responsive, enhance anti-interference ability, and robust to parameter changes, which can greatly improve the overall performance of the whole system.

3. Vehicle control technology

The new electric vehicle control system is a two-bus network structure, namely the high-speed CAN bus of the drive system and the low-speed bus of the body system. Each node of the high-speed CAN bus is the ECU of each subsystem, and the low-speed bus sets the node according to the physical location. The basic principle is regional autonomy based on spatial location.

To realize the network control of the whole vehicle, it is necessary to solve the problem of complicated lines and the increase the electronics of automobiles. However, the communication and resource sharing ability realized by the network has become a basis for the application of new electronic and computer technologies in automobiles. It also provides strong support for X-by-Wire technology.

4. Vehicle lightweight technology

Vehicle lightweight technology has always been an important research content of automotive technology. Since electric vehicles are equipped with battery packs, the quality of the whole vehicle is increased more, and the problem of lightweight is more prominent. The following measures can be taken to reduce the quality of the whole vehicle.

(1) Analysis of the actual working conditions and usage requirements of the whole vehicle, the overall optimization of the vehicle's voltage, capacity, motor drive power, speed, torque, vehicle performance and other vehicle parameters such as reasonable selection of batteries and motors.

(2) Reduction of the quality of powertrain and vehicle energy system through structural optimization and integration of modular optimization design.

This includes integrated and modular design of the motor and drive, drive train, cooling system, air conditioning and vacuum brake system to optimize the system, vehicle energy system consisting of battery, battery box, battery management system, and car charger reasonable integration and dispersion to achieve system optimization.

(3) Actively adopt lightweight materials, such as the structural frame of the battery box, the cover of the box, the hub, etc., using lightweight alloy materials.

(4) Using CAD technology to carry out finite element analysis on the load-bearing structural members (such as front and rear bridges, new side beams, beams, etc.), and use calculation and experiment to achieve structural optimization.

1.7 Overview of driverless vehicle

The concepts related to terminology of driverless cars include auxiliary driving, active safety, autonomous driving vehicles and intelligent vehicles. Among them, intelligent vehicles contain the widest range. It covers auxiliary driving, active safety and autonomous driving. It has gradually realized auxiliary driving and active safety in the process of intelligent development. Autonomous driving is the ultimate direction of intelligent vehicle development. The law of self driving vehicle developed by California state states that "self driving vehicle" means the use of computers, sensors and other technologies and equipment to enable vehicles to run safely without active control and continuous monitoring of drivers. It can be seen that the driverless vehicle is a form of autonomous driving. It has all the control functions related to vehicle safety in the whole road environment, and does not require drivers to control vehicles.

The driverless vehicle is able to be put on the research agenda of the major automobile enterprises. The research institutes at home and abroad have invested a lot of manpower and material resources as a research focus, from military applications to civilian development, not only because it represents the high and new technology level, but also because it meets the urgent demand for the development of automotive technology. The continuous improvement of highway grades, the rapid development of expressways, the rapid increase of vehicle speed and the large increase of vehicle ownership mean that the traffic system demands more and more people's driving technology. The frequent occurrence of traffic accidents is not only a number of data, but an important problem affecting people's lives. In the field of automotive technology development, technology is generally believed to be more reliable than human beings. A European study shows that drivers can avoid at least 60% of rear end collision accidents, 30% of face crash and 50% of road related accidents before they can get "0.5s" before collision risk. If 1s has "early-warning" time, 90% of accidents will be avoided. The study also shows that if technology is used to replace human driving, traffic accidents are expected to be reduced to zero. In particular, the combination of the driverless vehicle and the vehicle network forms a huge mobile couplet network. Combined with the abundant road traffic information provided by the existing intelligent transportation system, the driverless vehicle can travel more freely and safely in the urban road environment, and in turn, it will form a more intelligent transportation system. Its value and significance lie in: greatly improving the capacity of the highway, reducing traffic congestion and congestion on a large scale, reducing vehicle fuel consumption, and reducing the losses caused by urban traffic congestion and congestion.

Although fully automated driverless cars have not yet been able to enter the lives of ordinary people, many kinds of auxiliary driving functions, such as adaptive speed control and automatic emergency braking, have appeared in the market. This enables the semi autonomous driving vehicle to become a reality for first times in many areas of the automotive market. According to a survey by relevant research institutions, first unmanned vehicles may be put into production in 2020. Driverless cars will be an inevitable trend in the development of the automotive industry, and China will also become a big sales country for driverless cars [5].

1.8 Chinese and foreign research status

At present, there are researches on miniature unmanned vehicles at home and abroad. Domestic products are represented by Wobida unmanned distribution logistics vehicle, Neolithic unmanned logistics vehicle and Shenlan Technology's small eagle logistics robot. The Wobida unmanned distribution logistics vehicle is equipped with the AVOS system independently developed by Chihiro Technology, providing multi-sensor adaptive fusion algorithm, environmental recognition algorithm, well-designed path planning algorithm, high-reliability control algorithm and intelligent distribution. The solution can realize humanized and intelligent automatic logistics distribution. The Neolithic unmanned logistics vehicle is an L4-class unmanned micro-logistics vehicle developed on the basis of Baidu's MicroCar-unmanned trolley solution. This unmanned vehicle can be landed on warehouses, parks, factories and other scenes. Improve logistics efficiency while reducing labor costs. The small eagle logistics robot is an unmanned intelligent logistics robot. It has many functions such as autonomous driving, GPS positioning, active obstacle avoidance, and planning driving routes. It can distribute various products such as take-out and express delivery to achieve the last mile. Automated delivery, automatically reach the user via voice call after picking up the destination. The foreign research is represented by Nuro Corporation in Silicon Valley, USA. Just recently it announced its withdrawal from the L4-class fully automatic unmanned delivery vehicle. In the current global autonomous driving project, Nuro will be one of the first products to be commercialized in the L4 phase (completely unmanned). This is a completely driverless, ground-based unmanned delivery electric vehicle which was designed according to the vehicle specification. That is to say, the product is not designed for low-speed parks or sidewalks, but can be driven on motor vehicle lane in most cities, and the speed is not too slow. This shows that researchers in China and abroad have invested a lot of energy and capital in the field of unmanned logistics vehicles and obtained a series of research results. The autonomous driving and logistics industry naturally can be easy combined and the logistics industry is the best experimental field for commercialization of autonomous driving[6].

Chapter 2 The form of unmanned pure electric logistics vehicle and the choice of main parameters

2.1 Choice of car form

Different types of cars are mainly distinguished by the number of axles, the form of drive and the form of arrangement. The car can have two axes, three axes, four axes or even more. The factors affecting the number of axes to be selected are the total mass of the car, the restrictions on the axle load quality of the road regulations, the load capacity of the tires, and the structure of the car. The car drive form has 4×2, 4×4, 6×2, 6×4, 6×6, 8×4, 8×8, etc., where the previous digit represents the total number of car wheels, and the last digit represents the drive wheel. number. The use of the car, the total mass and the requirements for the passing performance of the vehicle are the main factors affecting the selection of the drive form. Increasing the number of driving wheels can improve the passing ability of the car. The more the number of driving wheels, the more complicated the structure of the car, the increase in the quality of the kerb and the manufacturing cost, and the difficulty in the overall layout of the car. Passenger cars and commercial vehicles with a lower total mass are often used in a 4×2 drive form with a simple structure and low manufacturing cost. The arrangement refers to the interrelationship and arrangement characteristics of the engine, the transaxle and the body (or the cab). In addition to the relevant parameters of the vehicle and each assembly, the layout of the vehicle also has an important influence on the performance.

Based on the reference parameters and structural characteristics of the reference vehicle, the axle number is 2, the driving form is 4X2, and the layout is prepositioned[7].

2.2 Selection of main parameters

2.2.1 Main dimensions

According to the graduation design task book requirements, the relevant size requirements are as follows：

Outside dimensions：2500mm/1000mm/1800mm

Wheelbase：1730mm

Front and rear track：$B1 = B2 = 820mm$

Front overhang：$L_F = 370mm$，rear overhang： $L_R = 400mm$

2.2.2 Quality parameter

Vehicle kerb quality：$700kg$

Loading quality：$300kg$

Total vehicle quality：$1000kg$

Axle load distribution：

The axle load distribution of a vehicle refers to the vertical load of each axle to the support plane under no-load or full-load static state, and can also be expressed as a percentage of the total mass of the idling or full load.

Axle load distribution has an impact on tire life span and many of the car's performance. From the point of uniform wear and life span of each tire, the load of each wheel should be similar. In order to ensure good power and passability of the car, the drive axle should have sufficient load. The load on the driven shaft can be appropriately reduced small, in order to reduce the rolling resistance of the driven wheel and improve the passage on the loop surface. In order to ensure good steering stability of the car, the load of the steering shaft should not be too small. Therefore, it can be obtained as a very important axle load distribution parameter, and the performance requirements are contradictory to each other. This requires that the axle load distribution should be reasonably selected according to the performance requirements and use conditions of the vehicle[8].

The driving form of the car, the engine position, the structural characteristics of the car, the form of the front and the usage conditions have a significant impact on the axle load distribution. For example, the engine front-wheel drive passenger car and the flat-head commercial truck have a large front axle load, while the long-head truck has a small front axle load. For off-road vehicles that often travel on bad roads, the front axle load should be smaller. We can select axle load distribution according to table 2.1.

Since the layout is pre-precursor, take:

Full load: 55% for the front axle and 45% for the rear axle;

No load: 60% for the front axle and 40% for the rear axle.

2.2.3 Determination of performance parameters

Maximum speed：50km/h

Maximum gradient：20%

Table 2.1 Axle Load Distribution of Vehicles

	Type	Full Load		No Load	
		front axle	rear axle	front axle	rear axle
Passenger car	FF	47%～60%	40%～53%	56%～66%	34%～44%
	FR	45%～50%	50%～55%	51%～56%	44%～49%
	RR	40%～46%	54%～60%	38%～50%	50%～62%
commercial car	4x2 Rear wheel with single tire	32%～40%	60%～68%	50%～59%	41%～50%
	4x2 Rear wheel with double tire, long or short head	25%～27%	73%～75%	44%～49%	51%～56%
	4x2 Rear wheel with double tire, flat head	30%～35%	65%～70%	48%～54%	46%～52%
	6x4 Rear wheel with double tire	19%～25%	75%～81%	31%～37%	63%～69%

Chapter 3 Matching of power system and transmission system parameters

3.1 Motor parameter design

The matching of the power parameters of the driving motor does not only affect the dynamic performance of the electric vehicle directly, but also affects the economic performance of the whole vehicle due to the efficiency problem of the actual working point of the motor. When the motor power is too large, more the backup power is required, so that the vehicle's power performance will be better. But, when the motor is often under load, the efficiency and power factor will be pulled down and the higher the power, the more the motor quality and volume. This affects the economic performance of the vehicle. When the motor power matching is small, the motor is often in an overload state, and the damage to the motor is also large. There are two indicators for the matching of the motor drive power parameters, namely rated power and peak power. Generally, the peak power is 2-3 times the rated power, but the motor can only output the peak power for a short time. The maximum speed requirement of an electric vehicle can be smoothly and continuously operated. In the matching principle, the power consumed by the motor at the highest speed is matched to the rated power of the motor, and the vehicle climbing and acceleration performance are short-time overload driving, and the consumption thereof is used. Power to match the peak power of the motor.

（1）The rated power of the generator based on the maximum speed is determined by[9],

$$P_{mr} = \sum_{u_{amax}} P = \left(\frac{Mgf}{3600} u_{amax} + \frac{C_d A u_{amax}^3}{76140}\right) / \eta_t \tag{3.1}$$

Take $C_d = 0.7$，M=ma=1000kg,Uamax=50,A=1.8,g=9.8, $\eta_t = 90\%$,f=0.02

After calculation：$P_{mr} = 5.32kw$

（2）motor power based on car grade is determined by,

$$\sum_i P = \left(\frac{Mgf}{3600} u_a + \frac{C_d A u_a^3}{76140} + \frac{Mgi}{3600} u_a\right) / \eta_t \tag{3.2}$$

Here Ua=10km/h

After calculation：$\sum_i P = 6.66kw$

（3）Motor peak power is given by,

$$P_{mmax} = \sum_i P = 6.66kw$$

3.2 Motor selection

The permanent magnet synchronous motor has the characteristics of high efficiency, high control precision, high torque density, good torque stability and low vibration noise. By reasonably designing the permanent magnetic circuit structure, high magnetic field performance can be obtained, and then the electric vehicle is driven. This type of motor has high application value, so the permanent magnet synchronous motor is selected as the motor drive. According to the above relevant data, Shanghai Electric Drive 6kw low-speed electric vehicle motor is selected,

Table 3.2 Driving motor parameters

Motor type	Permanent magnet synchronous motor
Rated voltage	60
Rated power	6
Peak power	12
Rated speed	3000
Peak speed	5300
Rated torque	20

Peak torque	72

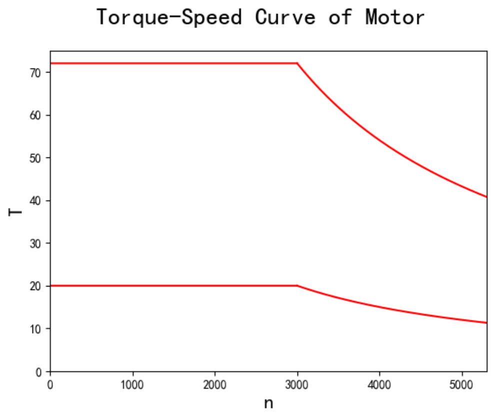

Figure 3.1 Torque-Speed Curve of Motor

3.3 Drive train ratio design

Due to the high speed of the motor, it is not possible to directly drive the wheels of the vehicle. Usually, a large speed ratio reducer or a two-speed transmission is used in the drive system. The function is to decelerate and increase the twist. The reverse gear is not set in the reducer or the transmission, and the reverse is realized by the reverse rotation of the motor. When the output characteristics of the motor are constant, the choice of the transmission ratio depends on the dynamic performance requirements of the vehicle[10].

（1）Driveline ratio upper limit

Maximum motor speed n_{max} and maximum vehicle speed u_{amax} are used to determine the driveline ratio upper limit as,

$$\mathrm{r} = 0.2837\mathrm{m}$$

$$\sum i \leq \frac{0.377 n_{max} r}{u_{amax}} = \frac{0.377 \times 5300 \times 0.2837}{50} = 11.3 \tag{3.3}$$

i：Drive train total ratio

n_{max}：Motor maximum speed（r/min）

r：Wheel radius（m）

（2）Drive train ratio lower limit

The maximum value of the transmission gear ratio is calculated by the two methods..

Using maximum output torque corresponding to the maximum speed of the motor given by,

$$T_{nmax} = 11.3$$

$$F_{uamax} = Mgf + \frac{C_d A u_{amax}^2}{21.15} = 345N \tag{3.5}$$

$$\sum i \geq \frac{F_{uamax} r}{\eta_t T_{nmax}} = \frac{345 \times 0.2837}{0.9 \times 11.3} = 9.6 \tag{3.4}$$

F_{uamax}： Driving resistance corresponding to the highest speed (N)

T_{nmax}： Output torque corresponding to the maximum motor speed (N.m)

Using maximum output torque of the motor and the running resistance corresponding to the maximum grade given by,

$$F_{imax} = \quad Mgf + \frac{C_d A u_a^2}{21.15} + Mgi = 2162\text{N}$$

$$\sum i \geq \frac{F_{imax} r}{\eta_t T_{max}} = \frac{2162 \times 0.2837}{0.9 \times 72} = 9.5$$

F_{imax}：Driving resistance corresponding to the maximum grade（N）

T_{max}：Motor maximum output torque (N · m)

Take the drive train transmission ratio as 10.

3.4 Battery pack capacity design

When matching the power battery, the number of required batteries and the rated discharge capacity should be calculated according to its performance requirements. It is also important to evaluate and select the comprehensive performance of the battery. As the only power source for electric vehicles, power batteries should be safe and reliable, have higher specific power and specific energy, longer discharge cycle life, and have good market cost performance. The ternary lithium battery is selected and the voltage platform is high. The voltage platform is an important indicator of the energy density of the battery, which determines the basic performance of the battery. The voltage platform of the ternary material is significantly higher than lithium iron phosphate, the high line can reach 4.2 volts, and the discharge platform can reach 3.6 or 3.7 volts. In terms of power battery parameter matching, the voltage level of the high-voltage system of the logistics vehicle is matched with the number of single-cell batteries and the series-parallel mode, and then the required battery rated capacity is calculated according to the 100km constant-speed driving mileage requirement[11].

（1）Match the number of single cells

The standard voltage V_0 of the ternary lithium ion battery is 3.6V, and the motor voltage is 60V.

$$\mathrm{N}=\frac{V}{V_0}=\frac{60}{3.6}=16.7$$

Let it equals to 17.

Electric energy required to drive 100 km

$$\mathrm{W}=\frac{\mathrm{S}\cdot \mathrm{P}_{mr}}{u_a\cdot \eta_t\cdot \eta_m}=\frac{100\times 5.32}{50\times 0.9\times 0.8}=14.8kw\cdot h \tag{3.6}$$

η_m： Motor and motor controller total efficiency

Power battery rated capacity

$$\mathrm{C}\geq\frac{W}{N\cdot V_0\cdot \mathrm{DOD}\cdot \eta_b}=\frac{14.8}{17\times 3.6\times 0.9\times 0.98}=274.2A\cdot h \tag{3.7}$$

DOD: depth of discharge

η_b: discharge efficiency

Choose CATL3.65V70AH ternary power lithium battery, battery capacity is 70Ah, then need to be connected in parallel

$$\mathrm{n}=\frac{274.2}{70}=3.9$$

Let it equals to 4.

（2）Check if the maximum power required by the car is met

$$P_{sbmax} = V_0 \cdot I_{smax} \tag{3.8}$$

$$(n \cdot N \cdot P_{sbmax})\eta_m = (4 \times 17 \times 3.65 \times 70) \times 0.8 = 13.9kw \geq P_{mmax} \tag{3.9}$$

P_{sbmax}: maximum discharge power of single cell

η_m: total efficiency of motor and controller

I_{smax}: maximum discharge current

（3）Check the cruising range

$$\mathrm{W} = C_e \cdot V_0 \cdot n \cdot N \cdot DOD = 70 \times 3.65 \times 4 \times 17 \times 0.9 = 15.6kw \cdot h \tag{3.10}$$

$$\mathrm{S} = \frac{\mathrm{W} \cdot u_a \cdot \eta_t \cdot \eta_m}{P_{mr}} = \frac{15.6 \times 50 \times 0.9 \times 0.8}{5.32} = 106\mathrm{km} \tag{3.11}$$

This meets the 100km driving range requirement.

Chapter 4 Selection of chassis assembly

4.1 Tire selection

Radial tires are characterized by low rolling resistance, low temperature rise, carcass cushioning performance and tread adhesion performance. They are better than bias tires. They have low fuel consumption, long wear life and high speed performance[12]. They are suitable for modern vehicles. High-speed, low-energy development requirements, so radial tires are selected, with specifications of 115/70 R16.

4.2 Selection of other components and assemblies

（1）Universal transmission device

The side of the half shaft close to the differential uses a telescopic ball cage universal joint, and the side of the steering wheel is a Birfield type ball cage universal joint. This compensates for track changes due to front wheel bounce and load changes.

（2）Reducer

By using two-stage cylindrical gear main reducer, the clearance between ground and ground can be guaranteed, and a larger transmission ratio can be obtained at the same time.

（3）Differential

The bevel gear differential is selected, which has the advantages of simple structure, small mass and the like, and is widely used.

（4）Drive axle type

The disconnected central two-stage deceleration front steering axle is used. The structural feature of the disconnected drive axle is that there is no rigid integral casing or beam connecting the left and right drive wheels, and the final drive, the differential and the housing are mounted on the frame or the body, and the wheels are driven by the universal joint. The drive wheels on both sides are elastically connected to the frame or the body via independent suspensions, so that they can swing up and down independently of the frame or the body.

（5）Suspension

The front suspension adopts the MacPherson independent suspension, which can increase the space inside the two front wheels and facilitate the arrangement of the engine and other components. The elastic component is a coil spring, and the shock absorber selects the double-acting cylinder damper; The suspension adopts a torsion beam type independent suspension, which is characterized in that the rubber-metal support is an asymmetric rubber wedge structure, and the radial elasticity is small and the axial elasticity is large. When the car is turning, the structure can eliminate the self-steering of the rear axle and maintain the steering characteristics of the original designed car. The elastic element is a coil spring, and the damper selects a bidirectional action barrel damper.

（6）Braking system

A regenerative-hydraulic hybrid brake system is used. The front brake uses a floating caliper disc brake, which is simple and compact in structure and easy to install. The rear brake uses a hoist-type brake, which is low in cost and has the same braking performance when moving forward and backward. A wheel brake drum parking brake system is used.

（7）Steering system

Electric power steering system, rack and pinion steering gear. The servo motor drives the steering input shaft to rotate through the gears to realize the steering function.

Chapter 5 Body styling design

The target vehicle of this design is a small logistics vehicle, so it can refer to the design of freight cars as a whole. The design language of the arcing is taken for the front of the vehicle[13]. Considering the vehicle type is a small truck, there is a certain requirement for the load capacity of the vehicle. Therefore, it is not suitable to choose the load-bearing vehicle body. For the container part, the interior is designed as a detachable partition space, which is conducive to the flexible layout of various goods [14].The export of goods is set at the rear and side of the container. The design of the export is designed to meet the principle of large opening under the condition of structural permission, so as to facilitate the loading and unloading of goods. The camera at the top of the car and the lidar are mounted on the front, which helps to increase the detection range of the camera. Because the ultrasonic radar has a small detection range, it is placed at a lower position. Choose a detachable container, which can maximize the use of logistics vehicles, different cargo uses different containers, to minimize logistics costs. The body diagram is shown in Figure 5.1.

Figure 5.1 Body Shape Diagram

Chapter6 Selection of driverless system

6.1 Environmental awareness system

In the driverless technology, environment-aware technology is an important part of it. It directly determines the overall level of driverless cars and has always been the focus of research in driverless technology[15].The environmental awareness system focuses on various radar sensors and camera technologies, such as laser radar and ultrasonic sensors. A laser radar is a radar system that emits a laser beam to detect a target position. Most of them rely on rotating mirrors to emit laser light and measure the distance by measuring the time difference between the emitted light and the light reflected from the surface of the object. The ultrasonic sensor is a sensor developed by utilizing the characteristics of ultrasonic waves. The data processing of this sensor is simple and fast, but the detection distance is short, and it is mainly used for short-distance obstacle detection. After comprehensive consideration, one 16-line laser radar is mounted on the top of the car; one RTK antenna on the second floor is used to achieve high-precision positioning, the middle binocular camera; the third layer is equipped with four cameras surrounding the body; the bottom layer is set. 8 ultrasonic sensors around the body. This layout can meet the unmanned requirements of logistics vehicles.

6.2 Decision planning system

The behavioral decision-making system is a narrow decision-making system. It reasonably determines the behavior of the current vehicle based on the information output by the sensing layer, and determines the constraints of the trajectory planning according to different behaviors, and guides the trajectory planning module to plan the appropriate path, vehicle speed and other information. Send to the control layer. The decision-making algorithm based on rules and learning-based is used to make use of the advantages of learning algorithms, reduce data dependence and ensure the correctness of decision structure. In the positioning and navigation, the GPS/DR combined positioning system is adopted to combine the global positioning system and the track estimation system to improve the system accuracy and enhance the anti-interference ability and tracking capability of the system. In the path planning, real-time and incremental path planning based on variable-dimensional state space is adopted, which is also real-time and incremental, and is used to solve the real-time path planning problem under uncertain environment.

6.3 Control execution system

Since the logistics vehicle designed this time has no driver, the servo motor can be used to drive the steering input shaft to rotate according to the signals of the environment sensing system and the decision planning system, thereby realizing the steering function.

The servo motor is used to push the push rod according to the signals of the environment sensing system and the decision planning system, and the rotational force of the motor is converted into a linear motion force by the ball screw, and the ball screw also functions as a speed reducer, reducing the motor speed and increasing the torque, and pushing The master cylinder piston achieves braking.

Chapter 7 Car performance analysis

7.1 Check the maximum speed

Graphical analysis of the vehicle's driving equation can obtain the driving force resistance balance map.The maximum speed of the vehicle is checked by the driving force resistance balance map(Figure 7.1).

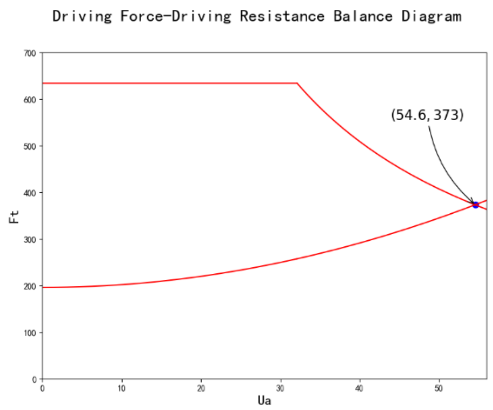

Figure 7.1 Driving Force-Driving Resistance Balance Diagram

It can be seen from the figure that the maximum speed meets the requirements.

7.2 Check the maximum grade

$$F_t = F_f + F_i + F_w + F_j \tag{7.1}$$

$$\mathrm{i} = \frac{\frac{T_{max} i \eta_t}{r} - Mgf - \frac{C_d A u_a^2}{21.15}}{Mg} \tag{7.2}$$

$$u_a = 10\,km/h$$

η_t: Mechanical efficiency of the drive train，take 0.9

After calculation:$\mathrm{i} = 0.212 > 0.2$

Use Python programming to draw a grade map

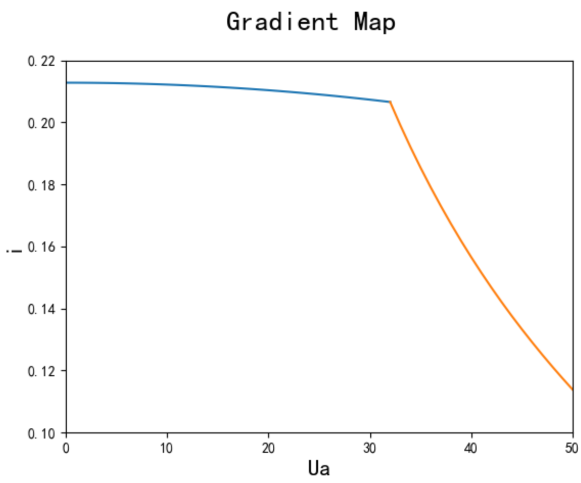

Figure 7.2 Gradient Map

7.3 Check the acceleration performance

According to the driving equation of the car, we can get

$$\frac{du}{dt} = \frac{1}{\sigma m}\left[F_t - (F_f + F_w)\right] \tag{7.3}$$

Then according to the existing data, Python programming can calculate the acceleration time of 0-50km/h at 7.7s, and draw the acceleration time curve and the inverse curve of acceleration.

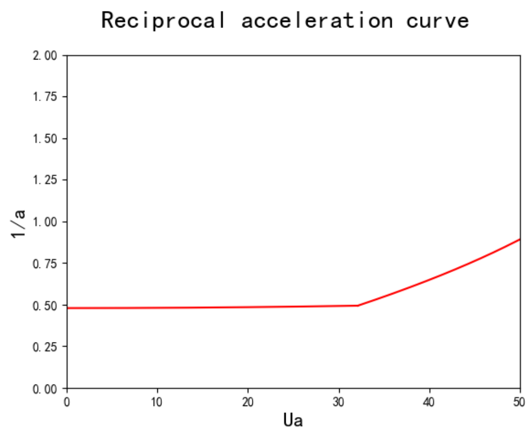

Figure 7.3 Reciprocal acceleration curve

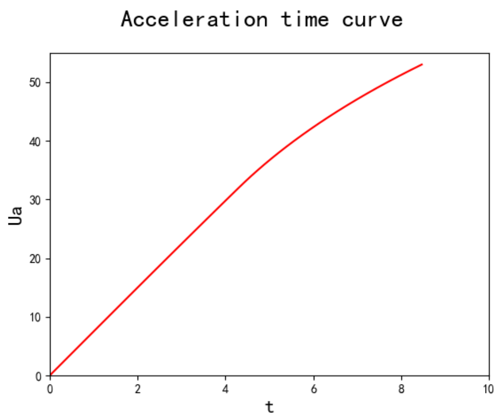

Figure 7.4 Acceleration time curve

7.4 Evaluation of brake performance

When the car is in motion, it can stop in a short distance and maintain the stability of the driving direction. The ability to maintain a certain speed when the road is down is called the braking property of the car. The braking performance of a car is one of the main properties of a car. Braking is directly related to traffic safety. Major traffic accidents are often related to the braking distance being too long and the side slip during emergency braking. Therefore, the braking performance of the car is an important guarantee for safe driving. Improving the braking performance of a car is always an important task for the automotive design, manufacturing and its usage . According to the relevant standards of automobile design braking performance, when the initial braking speed of the designed vehicle is $50\mathrm{km/h}$, the braking distance should not exceed $22\mathrm{m}$ at full load and $21\mathrm{m}$ at no load.

The height of the center of mass can be estimated by the following formula at no load

$$\mathrm{h}_{g1} = (0.38 \pm 0.02)\mathrm{h} \tag{7.4}$$

take

$$\mathrm{h}_{g1} = 0.7m$$

The height of the center of mass can be estimated by the following formula at full load

$$\mathrm{h}_{g2} = \mathrm{h}_{g1} + \Delta h \tag{7.5}$$

take

$$\Delta h = 20mm$$

get

$$\mathrm{h}_{g2} = 0.72m$$

At full load: select the road surface adhesion coefficient $\psi = 0.7$.

Take the synchronous adhesion coefficient

$$\psi_0 = 0.8$$

$$a = 1730 \times 45\% = 778.5\mathrm{mm}$$

$$b = 951.5\mathrm{mm}$$

$$\mathrm{h}_{g2} = 0.72m$$

According to

$$\psi_0 = \frac{l\beta - b}{\mathrm{h}_{g2}} \tag{7.6}$$

we can calculate

$$\beta = 0.87$$

Because

$$\psi_0 > \psi$$

the front wheel is locked first

$$E_f = \frac{\mathrm{z}}{\psi_f} = \frac{b}{L\beta - \psi_f \mathrm{h}_{g2}} = 0.95 \tag{7.7}$$

$$a_{max} = E_f \cdot \psi = 0.67\text{g} \tag{7.8}$$

$$\tau_2' = \tau_2'' = 0.2$$

$$\text{S} = \frac{1}{3.6}\left(\tau_2' + \frac{\tau_2''}{2}\right)u_a + \frac{u_a^2}{25.92a_{max}} = 17.6\text{m} < 22\text{m} \tag{7.9}$$

At no load：

$$a = 1730 \times 40\% = 692$$

$$b = 1038$$

$$\text{h}_{g1} = 0.7m$$

$$\beta = 0.87$$

Calculated at this time, the synchronous adhesion coefficient

$$\psi_0 = \frac{l\beta - b}{\text{h}_{g1}} = 0.67$$

Because

$$\psi_0 < \psi$$

the rear wheel is locked first

$$E_r = \frac{\text{z}}{\psi_r} = \frac{a}{L(1-\beta) + \psi_r \text{h}_{g1}} = 0.97$$

$$a_{max} = E_r \cdot \psi = 0.68\text{g}$$

$$\tau_2' = \tau_2'' = 0.2$$

$$\text{S} = \frac{1}{3.6}\left(\tau_2' + \frac{\tau_2''}{2}\right)u_a + \frac{u_a^2}{25.92a_{max}} = 17.4\text{m} < 21\text{m}$$

7.5 Evaluation of passability

Passability parameters can be measured on the side view of the car body, as shown in Figure 7.5.

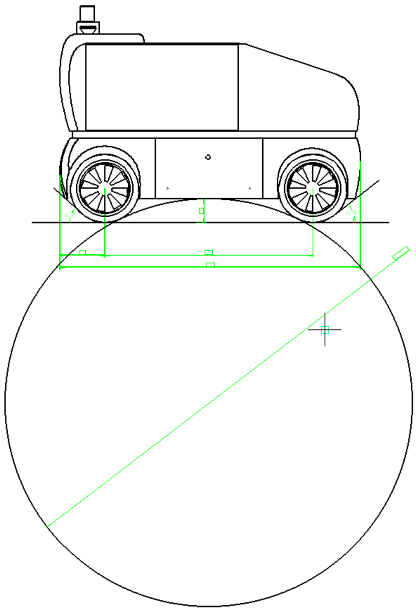

Figure 7.5 Body Side View

Minimum ground clearance：200mm

Approach angle： 42.86°

Departure angle： 37.97°

Minimum turning diameter：Select the outer steering wheel deflection angle

$$\alpha = 25^{\circ}$$

According to

$$\cot\alpha = \cot\beta + \frac{B}{L} \tag{7.10}$$

the inner steering wheel deflection angle can be calculated

$$\beta = 31^{\circ}$$

The ideal turning radius can be calculated

$$R_{min} = \frac{L}{\sin \alpha_{max}} = \frac{L}{\sin 25^{\circ}} = 4.094\text{m} < 6\text{m} \tag{7.11}$$

Longitudinal pass radius：2.2m

7.6 Evaluation of handling stability

There are many evaluation parameters for vehicle handling stability. We analyze the following parameters related to the overall design and can be used as design indicators.

(1) Steering characteristic parameters: In order to ensure good steering stability of the car, the car should have a certain degree of understeer. When the car is rotated along a fixed circle with a centering acceleration of 0.4g, the difference $\delta_1 - \delta_2$ between the front and rear wheel side angles is used as an evaluation parameter. This parameter is suitable for $1^{\circ} \sim 3^{\circ}$.

Use Carsim to analyze the whole vehicle, keep the car turning with a 0.4g centripetal acceleration along the fixed circle, and draw the centripetal acceleration map (Fig. 7.6) and the wheel side angle map (Fig. 7.7). The difference between the rear wheel side angles $\delta_1 - \delta_2$ is reasonable.

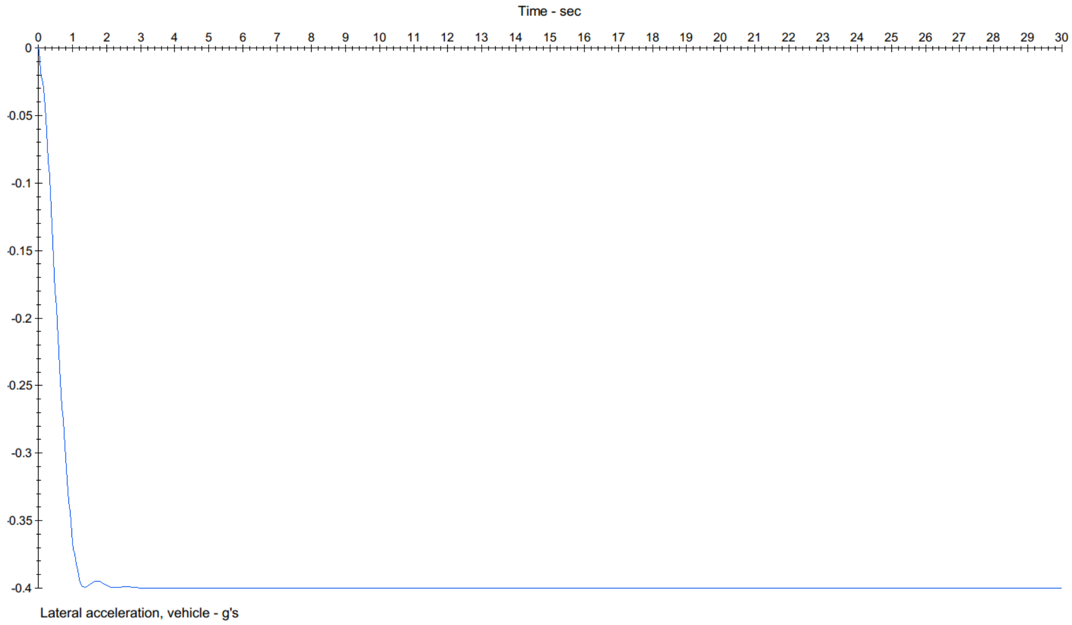

Figure 7.6 Centroidal Acceleration Diagram

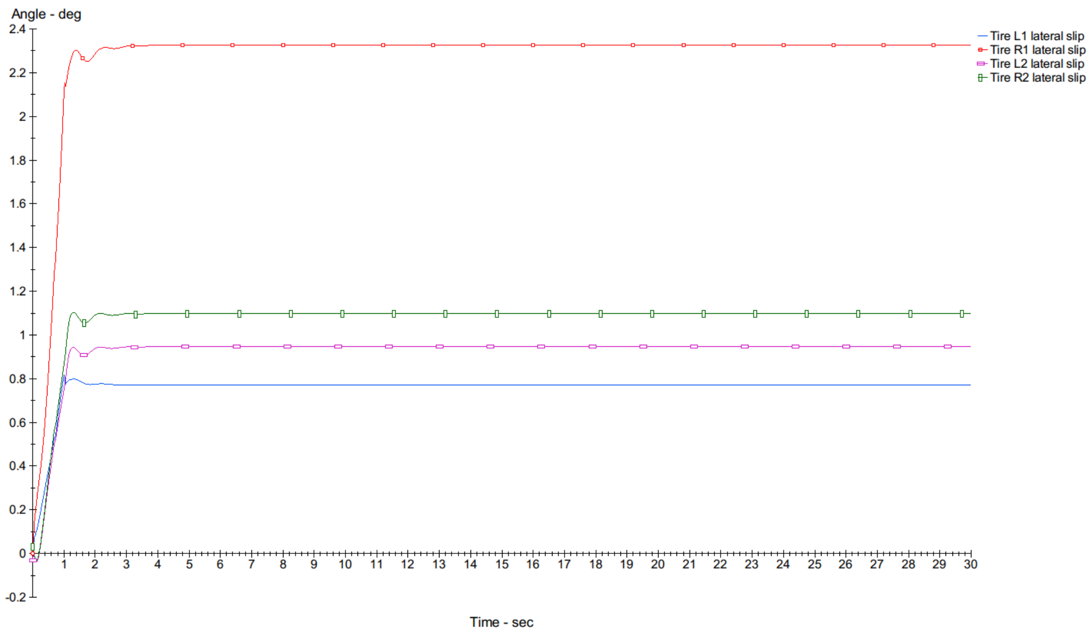

Figure 7.7 Side Deflection Diagram of Wheel

(2) Body roll angle: When the car travels at a constant speed of 0.4g with a centripetal acceleration, the body roll angle is controlled within 3°, and the maximum is not allowed to exceed 7°.

In the same working condition as the steering characteristic parameter simulation, the body roll angle diagram is drawn, as shown in Fig. 7.8. It can be seen from the figure that the body roll angle is 4°, which meets the requirements.

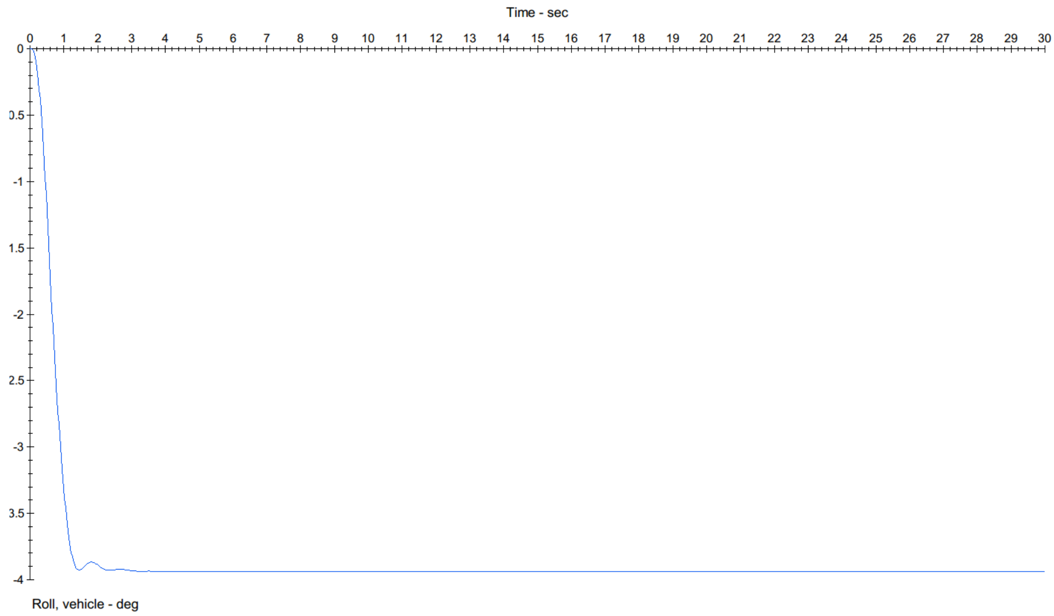

Figure 7.8 Body roll angle diagram

(3) Front bend angle of the car body: In order not to affect ride comfort, the car is required to brake at a deceleration of $0.4g$, and the front angle of the car body is not more than 1.5°.

In Carsim, the car is braked at a deceleration of $0.4g$. The deceleration diagram (Figure 7.9) and the front bend angle of the car body (Figure 7.10) are drawn. It can be seen from the diagram that the front bend angle of the car body is basically within 1.5°, which basically meets the requirements.

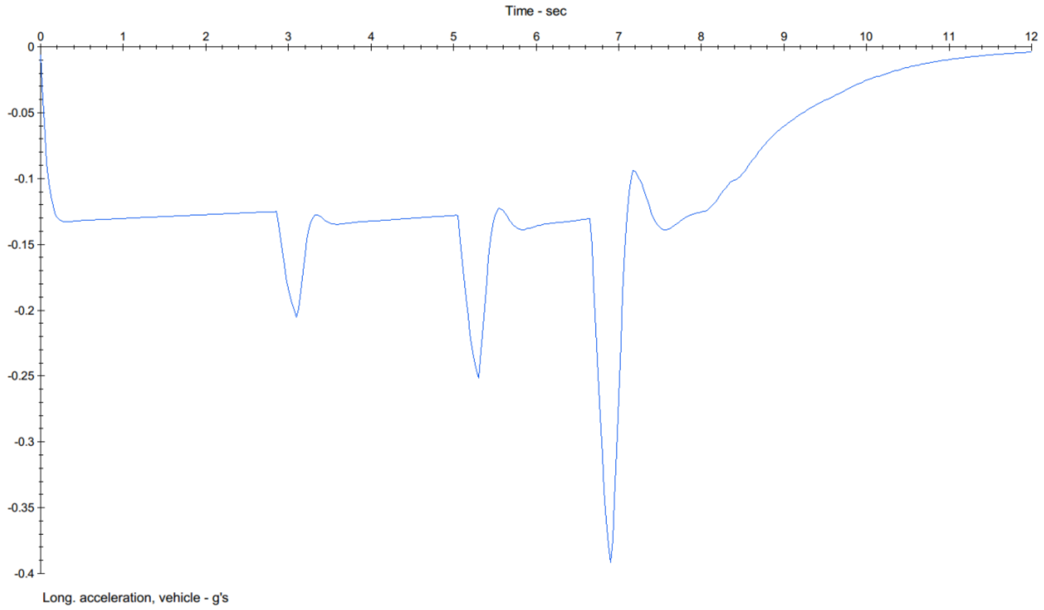

Figure 7.9 Deceleration Diagram

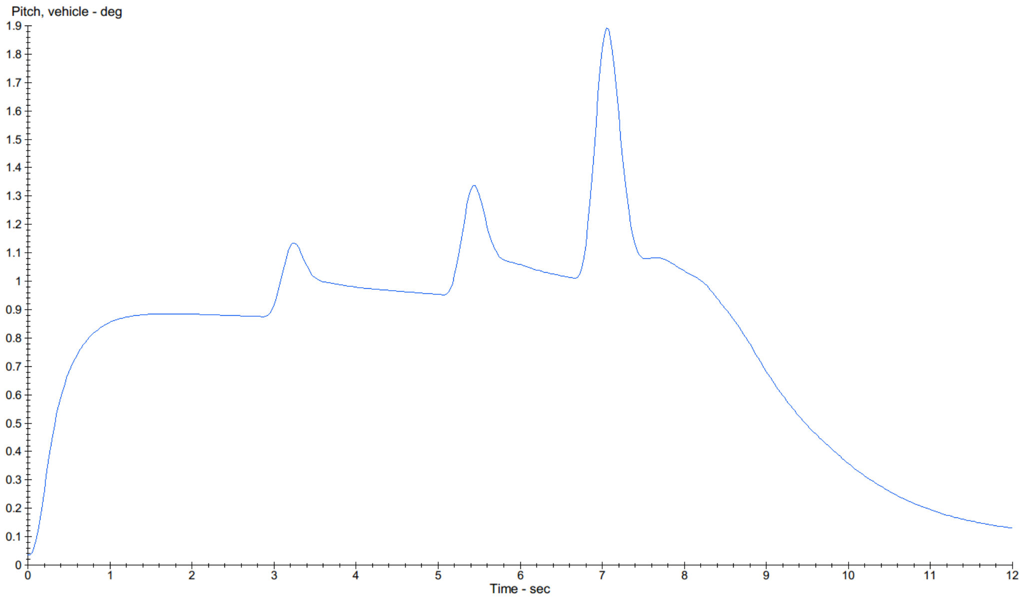

Figure 7.10 Front Bend Angle of Body

7.7 Ride comfort analysis

In this section, vehicle ride comfort is simulated, and weighted root mean square acceleration is used to evaluate the impact of vibration on cargo. In Carsim, the parameters of the vehicle are kept unchanged. Because there is no suitable road excitation data, the road excitation data in Carsim is adopted. In order to simplify the analysis, the evaluation of vehicle ride comfort only considers vertical acceleration. The vertical acceleration curve simulated by Carsim is shown in Fig. 7.11.

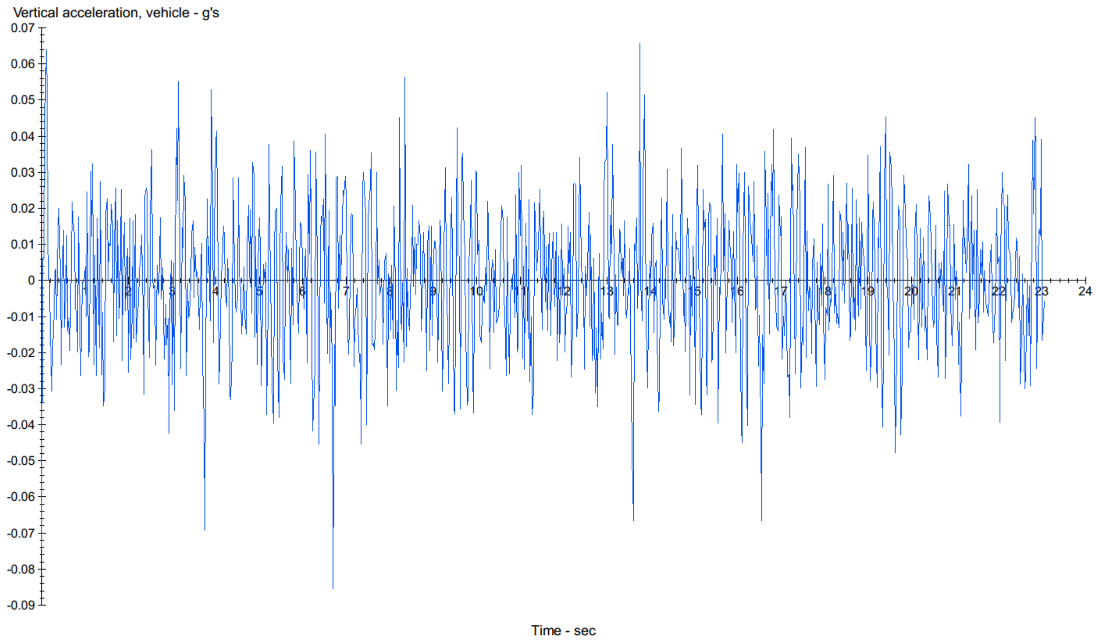

Fig. 7.11 Vertical acceleration curve

The data is exported to txt text format, then the acceleration data is read by Matlab software, and the power spectral density function $G_a(f)$ is obtained by spectrum analysis of the recorded acceleration time process. The power spectral density map is shown in Figure 7.12. Then, the weighted acceleration rms value is calculated according to the following formula.

$$a_w = [\int_{0.5}^{80} W^2(f)\, G_a(f) df]^{\frac{1}{2}} \tag{7.12}$$

We can use Matlab to caculate

$$a_w = 0.026 \ m/s^2$$

According to Table 7.1, there is no feeling of discomfort for people, and it can be considered that there is little influence on the goods on board.

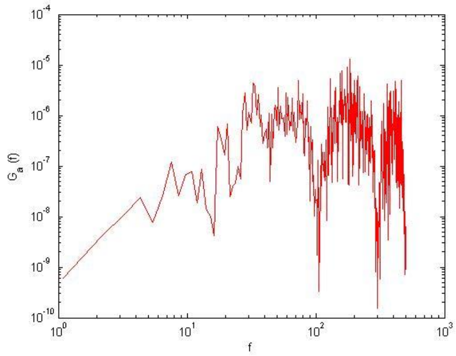

Fig. 7.12 Pavement excitation power spectral density

Table 7.1 The relationship between L_{aw} and a_w and human subjective sensation

Weighted root mean square acceleration a_w/（m/s^2）	Weighted vibration level L_{aw}/dB	Subjective Feeling
<0.315	110	No discomfort
0.315-0.63	110-116	Some discomforts.
0.5-1.0	114-120	Quite uncomfortable
0.8-1.6	118-124	Discomfort
1.25-2.5	122-128	Great discomfort
>2.0	126	Extremely uncomfortable

Chapter 8 Conclusion

In this paper, the overall design of unmanned electric logistics vehicles is carried out. Firstly, design principles of unmanned electric logistics vehicles were determined according to the relevant regulations and standards, and the overall design scheme is analyzed. The performance requirement of automatic driving is determined according to, the environment sensing system. Decision is taken to plan the systems type of control and execution arrangement system. The main technical parameters of the vehicle, including the main dimensions, quality and performance parameters are also determined. Next, the structural types, characteristic parameters and arrangements of the main assemblies of the chassis are determined. Throughout the calculation and analysis of the whole vehicle design, it shows that the overall design of the vehicle meets the requirements of power, driving range, braking performance, steering stability, ride comfort and passability.

Table 8.1 Vehicle parameters

Basic parameters	
Energy type	Pure electric
Driving range	106km
Maximum speed	54.6km/h
Acceleration time（0-50km/h）	7.7s
Maximum gradient（%）	20
Curb weight（kg）	700
Full load total mass（kg）	1000
body	
Length / width / height（mm）	2500/1000/1800
Wheelbase（mm）	1730
Front wheel pitch（mm）	820
Rear wheel pitch（mm）	820
Minimum ground clearance（mm）	200
Frame type	Side girder frame
Motor	
Motor type	Permanent magnet synchronous motor
Rated voltage（V）	60
Rated power（kw）	6
Peak power（kw）	12
Rated speed（rpm）	3000

Peak speed（rpm）	5300
Rated torque（Nm）	20
Peak torque（Nm）	72
Number of driving motors	1
Motor layout	Front transverse
Battery	
Battery type	Ternary lithium battery
Core nominal capacity（Ah）	70
Nominal voltage（V）	3.65
Internal resistance（Ω）	≤ 0.001
Standard discharge current（A）	70
Retarder	
Number of gears	1
Type of reducer	Fixed Tooth Ratio Two-stage
Chassis and Steering	
Driving mode	Front-end precursor
Front suspension type	McPherson independent
Rear suspension type	Torsion beam type independent
Assistance type	Electric power assist
Car body structure	Unloaded body
Tire and Braking	
Type of front brake	Vented Disc

Type of rear brake	Drum type
Parking brake	Wheel brake drum parking brake
Front tire specification	115/70 R16
Rear tire specification	115/70 R16

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Acknowledgement

After two months of hard work, I finally completed my undergraduate graduation project design. The whole design process is not too complicated. However, throughout the overall design of this car, I had more comprehensive understanding of the overall structure of electric vehicles.

I am used to admiring great men and celebrities, but I am more eager to dedicate my respect to no ordinary person than my teacher, Yu Houyu. I may not be your best student, but I have much respect for you. What impressed me the most was that you dedicated your time to answer all our question during this graduation project design period, which takes several hours and sometime affect your lunch time. For a small problem, you will think carefully and discuss it with us. This gives us a model for rigorous study.

At the same time, I would also like to thank the students in the group who have completed the graduation project with me. Many of the questions were answered in the process of discussing with you. I couldn’t successfully complete this graduation design without your help. At this juncture, my mood can't be calm. From the beginning of graduation project design to the successful completion of the defense, there are countless respectable teachers who have given me a lot of suggestions. Please accept my sincere gratitude here.

Finally, for those in the process of completing the thesis, I would like to express my heartfelt thanks to the teachers and students who care and help me.

Thank you all!

Appendix Program code

（1）acceleration_curve_py：

```
# -*- coding: utf-8 -*-
"""
Created on Mon Apr  1 23:05:49 2019

@author: Hans
"""

import matplotlib.pyplot as plt
from scipy import integrate
import numpy as np

M=1000;g=9.8;f1=0.02;Cd=0.7;A=1.8
Ff=M*g*f1
i=10
ηt=0.9
r=0.284

def f(Ua1):
    return  M/(72*i*ηt/r-M*g*f1-Cd*A*Ua1**2/21.15)

T=[]
for u1 in np.arange(0,33):
    v1,err=integrate.quad(f,0,u1)
```

```
    T.append(v1/3.6)
v,err=integrate.quad(f,0,32)


def f(Ua2):
    return M/(3000*72*0.377*r/Ua2/i*i*ηt/r-M*g*f1-Cd*A*Ua2**2/21.15)


for u2 in np.arange(33,54):
    v1,err=integrate.quad(f,32,u2)
    T.append(v/3.6+v1/3.6)


plt.plot(T,np.arange(0,54),color='r')
plt.suptitle('Acceleration time curve', fontsize=20, fontweight='bold')
plt.ylabel('Ua',fontsize=16)
plt.xlabel('t',fontsize=16)
plt.rcParams['font.sans-serif']=['SimHei']
plt.rcParams['axes.unicode_minus'] = False
plt.xlim((0, 10))
plt.ylim((0, 55))
```

（2）acceleration.py:

```
# -*- coding: utf-8 -*-
"""
Created on Tue Mar 19 10:26:28 2019


@author: Hans
"""
```

```
from scipy import integrate
import matplotlib.pyplot as plt


plt.rcParams['font.sans-serif']=['SimHei']
plt.rcParams['axes.unicode_minus'] = False


i=10
 η t=0.9
r=0.284


M=1000;g=9.8;f1=0.02;Cd=0.7;A=1.8
Ff=M*g*f1


def f(u1):
    return M/(72*i*ηt/r-M*g*f1-Cd*A*u1**2/21.15)
v1,err=integrate.quad(f,0,32)


def f(u2):
    return M/(3000*72*0.377*r/u2/i*i*ηt/r-M*g*f1-Cd*A*u2**2/21.15)
v2,err=integrate.quad(f,32,50)


print('T = %f s' %((v1+v2)/3.6))
```

（3）Acceleration_plot.py:

```
# -*- coding: utf-8 -*-
"""
```

```
Created on Mon Apr  1 23:58:03 2019

@author: Hans
"""

import matplotlib.pyplot as plt
import numpy as np
plt.rcParams['font.sans-serif']=['SimHei']
plt.rcParams['axes.unicode_minus'] = False
n1=np.arange(0,3000)
T1=72+n1*0
n2=np.arange(3000,5300)
T2=3000*72/n2


i=10
ηt=0.9
r=0.284
F1=T1*i*ηt/r
F2=T2*i*ηt/r
u1=0.377*r*n1/i
u2=0.377*r*n2/i

M=1000;g=9.8;f=0.02;Cd=0.7;A=1.8
Ff=M*g*f
Fd1=Cd*A*u1**2/21.15
```

```
Fd2=Cd*A*u2**2/21.15
a1=(F1-Ff-Fd1)/M
a2=(F2-Ff-Fd2)/M

plt.plot(u1,1/a1,color='r')
plt.plot(u2,1/a2,color='r')

plt.suptitle('Reciprocal acceleration curve', fontsize=20, fontweight='bold')
plt.ylabel('1/a',fontsize=16)
plt.xlabel('Ua',fontsize=16)

plt.xlim((0, 50))
plt.ylim((0, 2))
```

（4）gradient_plot.py:

```
# -*- coding: utf-8 -*-
"""
Created on Mon Apr  8 21:56:30 2019

@author: Hans
"""

import matplotlib.pyplot as plt
import numpy as np

plt.rcParams['font.sans-serif']=['SimHei']
```

```
plt.rcParams['axes.unicode_minus'] = False
M=1000;g=9.8;f1=0.02;Cd=0.7;A=1.8
Ff=M*g*f1
i=10
ηt=0.9
r=0.284

Ua1=np.arange(0,33)
i1=(72*i*ηt/r-M*g*f1-Cd*A*Ua1**2/21.15)/M/g
plt.plot(Ua1,i1)

Ua2=np.arange(32,51)
i2=(2988.75*72*0.377*0.284/10/Ua2*i*ηt/r-M*g*f1-Cd*A*Ua2**2/21.15)/M/g
plt.plot(Ua2,i2)

plt.xlim((0, 50))
plt.ylim((0.1, 0.22))

plt.suptitle('Gradient Map', fontsize=20, fontweight='bold')
plt.ylabel('i',fontsize=16)
plt.xlabel('Ua',fontsize=16)
```

（5）Motor_torque.py:

```
# -*- coding: utf-8 -*-
"""
Created on Wed Mar 27 11:43:24 2019
```

```
@author: Hans
"""

import matplotlib.pyplot as plt
import numpy as np
n1=np.arange(0,3000)
T1=20+n1*0
plt.plot(n1,T1,color='r')
n2=np.arange(3000,5300)
T2=3000*20/n2
plt.plot(n2,T2,color='r')
plt.plot(n1,(72/20)*T1,color='r')
plt.plot(n2,(72/20)*T2,color='r')
plt.xlim((0, 5300))
plt.ylim((0, 75))
plt.suptitle('Torque-Speed Curve of Motor', fontsize=20, fontweight='bold')
plt.ylabel('T',fontsize=16)
plt.xlabel('n',fontsize=16)
```

（6）tracing force_balance_plot:

```
# -*- coding: utf-8 -*-
"""
Created on Wed Mar 27 13:44:25 2019

@author: Hans
```

```
"""


import matplotlib.pyplot as plt


import matplotlib


import numpy as np


myfont = matplotlib.font_manager.FontProperties(fname=r'C:/Windows/Fonts/msyh.ttf')
plt.rcParams['font.sans-serif']=['SimHei']
plt.rcParams['axes.unicode_minus'] = False
n1=np.arange(0,3000)
T1=20+n1*0
n2=np.arange(3000,5300)
T2=3000*20/n2


i=10
η t=0.9
r=0.284
F1=T1*i*ηt/r
F2=T2*i*ηt/r
u1=0.377*r*n1/i
u2=0.377*r*n2/i


M=1000;g=9.8;f=0.02;Cd=0.7;A=1.8
Ff=M*g*f
```

```
Fd1=Cd*A*u1**2/21.15

Fd2=Cd*A*u2**2/21.15


plt.plot(u1,F1,color='r')

plt.plot(u2,F2,color='r')

plt.plot(u1,Fd1+Ff,color='r')

plt.plot(u2,Fd2+Ff,color='r')

plt.xlim((0, 56))

plt.ylim((0, 700))

plt.suptitle('Driving Force-Driving Resistance Balance Diagram', fontsize=20, fontweight='bold')

plt.ylabel('Ft',fontsize=16)

plt.xlabel('Ua',fontsize=16)


x0=54.6

y0=373

plt.scatter([x0, ], [y0, ], s=50, color='b')

plt.annotate(r'$(54.6,373)$', xy=(x0, y0), xycoords='data', xytext=(-100, 100),

             textcoords='offset points', fontsize=16,

             arrowprops=dict(arrowstyle='->', connectionstyle="arc3,rad=.2"))
```

（7）weighted_acceleration.m：

```
clc;

clear all;

data=textread('data.txt');

a=data(:,2);

t=0:0.025:23.05;
```

```
figure(1);
plot(t,a);


Fs=1000;
Nfft=length(a);
range='onesided';
window=hamming(length(a));
noverlap=0;
[Px,f]=pwelch(a,window,noverlap,Nfft,Fs,range);
figure(2);
plot(f,Px,'r');
xlabel('f');
ylabel('G_a (f)');
set(gca,'Xscale','log','Yscale','log');
acc_x=f;
acc_y=Px;
acc_num=0;
p=0;
i=1;


while i<length(acc_x)
    if acc_x(i)>0.5&&acc_x(i)<2
        ww(i)=0.5;
        p=2
    elseif acc_x(i)>=2&&acc_x(i)<4
        ww(i)=acc_x(i)/4;
```

```
    elseif    acc_x(i)>=4&&acc_x(i)<12.5
        ww(i)=1;
    elseif    acc_x(i)>=12.5&&acc_x(i)<80
        ww(i)=12.5/acc_x(i);
    else
        ww(i)=0;
    end
    acc_num=acc_num+ww(i)^2*acc_y(i)*(acc_x(2)-acc_x(1));
    i=i+1;
end
acc_Q=(acc_num)^0.5
```