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STUDY ON ENERGY SAVING OPTIMIZATION OF RAIL TRANSIT TRAIN OPERATION

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Abstract: This paper studies the energy-saving optimization decision-making of single or multiple trains in rail transit. Trains require a huge amount of energy, The research on the rational allocation of rail vehicles and the reduction of energy consumption in operation is of great significance. The complexity of the environment in which trains operate And the ups and downs of the track line, the force on the train is changing at any time. Realized by simulating rail train operation research The optimization model has great application value and theoretical significance. Using the principle of maximum value, multi-objective quadratic programming, nonlinear The equation model optimizes the energy consumed by rail trains, and in the case of energy optimization, the displacement, velocity and time, Regular transformation of speed.
Keywords: Urban train; Energy-saving operation; Timetable optimization; Matlab simulation

1 INTRODUCTION

With the pace of economic development, the function and importance of transportation to the country and society is like blood vessels to the human body. It is a pipeline for transporting nutrients, maintaining vitality and life. The development of the rail transit system not only brings convenience, safety, Comfortable transportation services represent progress and cultural advancement. Optimizing control to reduce train traction energy consumption is a key issue in rail transit One of the important directions of research in this field. Urban rail transit has the characteristics of low exhaust gas pollution, large carrying capacity, accurate running time and It has the advantages of fast speed and less land occupation. It alleviates the congested traffic situation in the city and greatly promotes social and social development. economic development. By optimizing the train speed-distance curve and stop interval time, the lowest energy consumption can be achieved. Standard [1].
The optimization of energy consumption in train operation has been studied a lot at home and abroad. Some scholars in Australia have used self-built energy consumption model type to solve. Some domestic scholars have discussed the optimization algorithm of train energy-saving maneuvering, and the numerical model of local optimization can be obtained by obtained by simulation, and then use the evolutionary algorithm to find the global optimum.

2 PROBLEM DESCRIPTION

When the train is running, the designed program will adjust the speed limit according to the characteristics of the train, the condition of the line, the line ahead, etc. degree is calculated. It is not allowed to exceed this limit speed during operation, and the limit speed will be updated periodically. Train operating conditions are limited Under the constraint of braking speed, there are four stages: traction, cruising, coasting and braking, and the traction force and resistance suffered by each stage are different. Optimizing energy-saving control For a single train, it is necessary to find the speed -distance curve so that it can meet the requirements of the total running time. The energy consumption of trains is the lowest; multi-station energy-saving optimization should consider the influencing factors of multi-train control, such as braking energy recovery and stop time And use etc[2].

3 ANALYSIS OF TRAIN RUNNING PROCESS

The main functions of each analysis module are as follows: The train operation simulation module is based on the train motion equation [3], equipped with Combining actual data such as train characteristics, track alignment, passenger load and operating parameters, to simulate a single train running on a track route during travel, and output the mileage and load information of each train for DC distribution in each snapshot (Snapshot) Analysis and rail potential and stray current analysis. The DC power analysis module is based on the train operation simulation and cooperates with the departure Timetable, place the trains on the route one by one at each simulation time, and place the equivalent train loads on the In the DC positive network, then the Newton - Raphson method is used to perform the DC load flow calculation, and finally output each snapshot moment Each train and TSS Load information is used for rail potential and stray current analysis [4]. Rail potential and stray current analysis module is based on the TSS at each snapshot moment during the simulation With the instantaneous power and voltage of the train, establish the busbar of the negative network stream source matrix Ibus, and at the same time cooperate with the negative network admittance matrix Ybus The establishment of the node current method to solve the negative network square Procedure Ibus = YbusVbus, get the voltage of each busbar in the negative network (including the rail potentials of the upper and lower rails), and according to the requirements The obtained bus voltage calculates the current of each branch (including the stray current of the upper and lower rails and each TSS The primary and secondary spurious current). In order to obtain accurate simulation results, the traction dynamic load analysis, rail potential analysis and stray current analysis in this paper A simulation interval of 0.1 second is adopted [5].

Traction dynamic load analysis, rail potential analysis and stray current analysis cover both normal and abnormal operating conditions. Normal operating conditions refer to all TSS are all online, and the traction power system is in normal operation [6], this Time train according to PTS It is stipulated that the maximum operating speed is 80 km / hr And the maximum acceleration and deceleration are both 1.0 m / s 2 turn; an abnormal operating condition means that there is a TSS in the system Fault offline, the traction power system is in abnormal operation At this time, in order to avoid the problem of insufficient power and excessive voltage drop, the maximum operating speed of the train is educed to 64 km / hr and the maximum The acceleration drops to 0.5 m / s 2 and the maximum deceleration maintains the characteristic operation of 1.0 m / s 2 [7].

4 PHYSICAL CHARACTERISTICS OF THE TRAIN

For the running train, the actual situation of its stress is very complicated. According to the single-mass model, the train is regarded as a single-mass point, and the train The moving force of the car is the traction force F, gravity G, braking force B with total resistance W Four categories, in line with Newton's laws of kinematics.

As shown in the picture As shown in Figure 1, the maximum value of train traction force is different at different speeds.

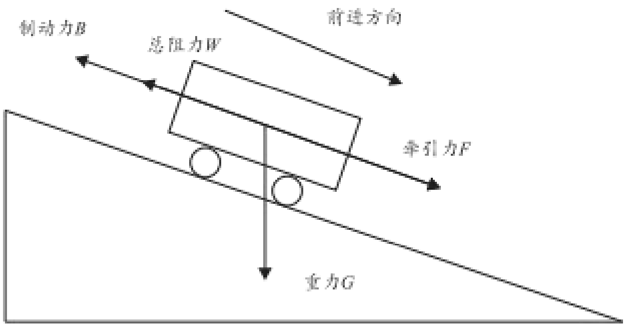

Fig. 1 Running curve between train stations

When the train is on a flat road or downhill, there is:

$$B + W = uF\max + G \times \sin\theta \tag{1}$$

When the rail train is on an uphill slope, there are:

$$B + W + G \times \sin\theta = uF\max \tag{2}$$

This article is based on the following assumptions: Assumption 1 is the deceleration stage of the train, the engine consumes no energy, and the energy consumption of the train air conditioner is small Neglecting it, the second assumption is that the train can be regarded as a mass point because the actual situation of the force on the rail train is very complicated [8]. Assumption three is The running train is only subject to total resistance and no other resistance. Assumption 4 is that the running trains can be braked and towed strictly according to the requirements, No human factor. Assumption 5 is the same as other conditions for all train power supply sections.

When the train travels between stations, there are several distance-velocity curves to choose from. Distance speed curve and corresponding operating time between stations different from energy consumption. The energy consumption and time of a train running between stations generally present an approximately inverse proportional relationship [9].

5 OPTIMIZATION OF ENERGY CONSUMPTION IN SINGLE TRACK TRAIN OPERATION

The resistance suffered by the train at different levels is a quadratic function of speed. The equation of motion for a single train is obtained as follows

$$dv \quad u\,f\,F\max - u\,b\,B\max - W \tag{3}$$

Where t (x), v (x) represent the displacement and velocity of the train at the distance, u b, u f braking force and traction force Number, W is the total running resistance, which includes g (x) due to the gradient of the road surface, which is positive when going uphill and is Negative. It can be concluded that the energy consumption model is as follows:

$$\min \quad J = \int_0 \text{north } u\,f\,F\max\,dx \tag{4}$$

here J Indicates the traction work, V (x) indicates the speed limit value at the corresponding distance, the optimization model (4) can be divided into the following Several kinds of noodles:

1) Maximum traction force for acceleration, u b = 0, u f = 1 ;
2) The braking force or traction force required to maintain constant speed running, that is, 0 < u f < 1, u b = 0 or u f = 0;
3) Neither braking nor traction, the train is in cruising state, ie u f = u b = 0 ;
4) The maximum braking force for braking, namely u f = 0, u b = 1. The analysis shows that in a road section, the total energy consumption is

$$E = \frac{v_4}{2b}(B - g(x)) - \frac{1}{b}\int w_0(v)\,v\,dv + gH + r\left(\frac{S}{T}\right)\cdot S \quad (5)$$

The proof of the equation is omitted.
the objective function can be defined as a nonlinear objective problem, and the constraints include time running, limited distance and speed, and the determination of Policy variable selection speed v_i is obtained by using the optimal control method.

6 OPTIMIZATION OF ENERGY CONSUMPTION IN MULTI-TRACK TRAIN OPERATION

In between is the cruising stage, between v_{i4} and v_{i5} is a constant speed stage, but the first and second parts are general slopes, then $v_{i4} = v_{i5}$. use j in each part Indicates each section, j = 1, 2, 3, 4. i Part j The velocity of the stage is v_{ij}, and easy Know $v_{i5} = v_{(i+1)1}$.
two stations is not single, and there are actually multiple slopes at each station. Therefore, according to the established The model of, depending on the distance between stations, divides N according to the speed limit block, labeled i, $i \in [1, N]$, each segment of running distance is $\triangle S_i$, Each running time is $\triangle T_i$, each speed limit is $v_{i\,lim}^{i}$. Based on the established single section model, the optimized control sequence Different in different parts. When the limited train speed is constant, there is no need to brake [10]. Divide each part into roughly Four control stages, in each part, the acceleration stage is between v_{i1} and v_{i2}, the constant speed stage is between v_{i2} and v_{i3}, and the cruise flight stage in Between v_{i3} and v_{i4}, the constant speed stage is between v_{i4} and v_{i5}, but because the general slope is the first and second parts, Therefore $v_{i2} = v_{i5}$. use j in each part Indicates each section [11], j = 1, 2, 3, 4. i Part j The velocity of the stage is v_{ij},and And it is easy to know that $v_{i5} = v_{(i+1)1}$.
According to the above single road condition model, it is easy to know that at i Unit energy consumption up to

$$\Delta E_i(v_{ij}, \Delta T_{ij}) = \frac{1}{2}v_{i4}^2 - \frac{1}{2}v_{i1}^2 + g\cdot\Delta H_i + \Delta E_i^{w0}. \quad (6)$$

You can refer to the model to calculate the running distance and time of each part, then you have to optimize the model

$$\min \quad E = \sum_{i=1}^{N}\sum_{j=1}^{4}\Delta E_{ij} \quad (7)$$

This model can be solved by applying the sequential quadratic rule (SQP) method. The total number of constraints is m, then there are n an equality constraint,
Inequality constraints have m − n indivual. The number of constraints depends on the number of subintervals and slopes. Rewrite the model as
no

$$\min \quad E = \sum_{i=1} E_i. \quad (9)$$

Construct the following Lagrangian function

$$L = E(y) + \sum \alpha_i C_i(y) \quad (10)$$

SQP is available for Lagrange functions Algorithm solution. Transforming linear values into nonlinear values is a programming subproblem.
The entire power supply line only uses one line, and the generated renewable energy can be used in each traction train, so the energy regeneration system For single power supply mode.
to utilizing regenerative braking energy is that when some trains brake, other trains Internal traction can absorb this part of the regenerative energy. Then adjust the cruising, traction, braking and coasting of the train During this period, the braking and traction of adjacent trains are matched, so that the utilization rate of regenerative energy can be improved. Considering the traffic system The proposed model does not consider the case where the distance between vehicles exceeds one station [12].
no When the car leaves i +1 station to accelerate, n +1 car enters i +1 station to decelerate, if n The car is in the same power supply area as the n + 1 car
segment, n The car can use the regenerative energy generated by n + 1 car braking; n When the car enters i +1 station and decelerates, n +1 car leaves i stand speed up if n car and n + 1 car are in the same power supply section, then n + 1 car can use n regenerative energy generated by braking Quantity to pull. Decreasing the total energy consumption of the entire line is the goal of setting energy-saving tables, and its correlation with regenerative braking energy and traction energy consumption is

$$W(H, H_9, 2H_4 - H_2, H_2 - H_4, H_1 - H_2, H_8)$$
$$= \sum_{i=1}^{n} W_i(H_9, 2H_4 - H_2, H_2 - H_4, H_{11}) - \sum w(H, H_9, 2H_4 - H_2, H_2 - H_4, H_1 - H_2, H_8).$$

According to the traction power of the train, the traction energy consumption W_i for

$$W_i = \int_{t=0} \sum_{i=0}^{N} T_i\, P\,dt. \quad (11)$$

7 SIMULATION EFFECT EVALUATION

Applying the subway information of Guangzhou Line 4, the embedding simulation platform for the evolution section implements rail train simulation, and analyzes the Compare the original scheme of the train with the obtained maneuvering scheme to verify the effectiveness of the algorithm.

7.1 Description of Simulation Conditions

The power supply of Guangzhou Line 4 subway uses the third rail mode, 1500 V is the grid terminal voltage. In the train four formations, loading staff Under the condition of constant load, the total train length is about 70.84.
The vehicle running resistance formula is $W_0 = 20.286 + 0.3822 v + 0.002058 v^2$ (N / KN), where the train running The velocity is v.

7.2 Algorithm Parameter Determination

The parameter range of genetic algorithm is: population size 20-30, crossover probability 0.5-1.0, mutation probability 0-0.05. Establish 5 sub-populations, each sub-population size is 20, and the 3 optimal individuals of each generation in each sub-population are among the sub-populations Migrate each other. Table 1 are the two probability values of crossover and mutation in the evolutionary segment.

Table 1 Calculation and Value Method of Crossover and Mutation Probability

initial t_2 (0, T_1]		Mid t_2 (T_1, T_2]	late t_2 (T_2, T]
Crossover probability (P_c)	1.00	0.90 _	0.80 _
Mutation probability (P_m)	0.05 _	0.03 _	0.01 _

Apply the above train conditions and routes, and use Matlab The software is the platform foundation, write the line, train information, train The running simulation uses the train maneuvering schemes of each group genetic algorithm respectively.
Through the evolutionary program, it can be seen that the results of optimizing multiple parallel group algorithms are obviously better than the simple algorithm of a single group, and the convergence More stable and faster.
According to the above evolution plan, the maximum generation of evolution is adjusted, so that the evolution effect of the solution is not affected, and the solution is shortened Operation time. The values of various parameters in the genetic algorithm are shown in Table 2 Shown.

Table 2 Genetic Algorithm Parameter Determination

number of subpopulations	subpopulation size	Number of individuals migrated	minimal chromosome length	crossover probability mutation probability	maximum /cross frequency	maximum evolution algebra
5	20	3	2	as table 6	10	80

8 SIMULATION ANALYSIS RESULTS

that affect the simulation results of train operation. In addition to the force change of the train itself, the distance and speed are also affected. work to a certain extent. Now use Matlab The software monitors the actual running situation of the train by setting parameters such as distance and speed. The optimal model is obtained through the simulation of the situation, which has obvious important theoretical significance and application value. The characteristic curve of distance and speed.
According to the simulation results, by establishing an energy consumption model to optimize a single subsection, and using the sequential quadratic programming method to solve the problem, the The train arrives on time and the energy consumption is reduced. Using this method can save energy by about 35%.
by factors such as energy consumption and distance to a certain extent. influence Now through Matlab Software, set parameters such as distance and energy consumption to simulate the simulation structure of the train in the actual driving process The results have very important theoretical significance and application value. Among them, the characteristic curve of distance and energy consumption.
Considering the utilization and recovery of braking energy, the maximum speed of the train does not drop significantly after energy-saving optimization, and the average full-line speed There is no major change, and the train running efficiency is not affected. However, the energy consumed across the board is reduced, and the most obvious stage of decline is 0– 2.0 km and 1.3–1.6 km, the energy saving effect is good. When two vehicles are tracking between stations [14], the running information of the vehicle in front is considered When it comes to the energy-saving driving of the following car, according to the energy-saving driving conditions of the two vehicles, these scenarios are classified as

optimizing the energy-saving results. The planned nonlinear model was established. Using this method can save energy by about 31%. According to the same passenger flow, without considering the size of passenger flow in different time periods. The size of passenger flow is actually It changes continuously with driving, and can continue to optimize the stop time. For example, we can divide the day into different periods to get a better train scheduling scheme.
Adjusting the braking energy at the departure interval can improve the utilization rate of regenerative energy and further reduce the total energy consumption of the whole line Low. The transportation capacity of rail cities is high, and the total energy consumption is high. The major problem to be solved is to reduce energy consumption [15].

9 CONCLUSION

This paper focuses on the analysis of the energy-saving operation of rail trains under traction mechanics, and the energy -saving control methods for trains on undulating ramps. Carried out research, constructed a mathematical model of energy-saving maneuvering trains under the condition of timing constraints, and gave and solved the given line Train operation optimization under the conditions. to Matlab Through software simulation, a train running scheme is designed, and energy consumption is reduced [16]. The simulation results show that by establishing an energy consumption model to optimize a single subsection, and using the sequential quadratic programming method to solve the problem, the train Arrive on time, system overhead is reduced. Using this method can save energy by 35% ; when two vehicles are tracking between stations, the The running information takes into account the energy-saving driving of the vehicle behind, and according to the energy-saving conditions of the two-vehicle tracking scenarios, these scenarios are optimal for energy saving., the construction planning model is nonlinear. Finally, the sequential quadratic programming method is used to solve the problem quickly. Simulations show that using the above The case can save energy by 31%.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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