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Parameter identification of dynamic model of semi-trailer train

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Abstract. In the study of semi-trailer vehicle stability control process, due to the high cost and high risk of actual vehicle experiment, a mathematical model of the vehicle is usually established to study the performance of the vehicle. However, some parameters in the model are difficult to obtain directly through the measurement or acquisition process cost is high, the application of parameter identification technology can effectively solve these problems. In order to accurately describe the dynamic characteristics of semi-trailer train, the dynamic model that involving the motion of yaw, lateral and rollover are established based on the vehicle dynamic theory. Taking advantage of Trucksim the key parameters of model are identified by using genetic algorithm combined with the L-M optimization algorithm. A simulation on the model in dynamic condition is carried out with the identified parameters. The comparisons of simulation results with Trucksim data indicate that the key identified parameters are more accurate and meet the requirements of the model for articulated semi-trailer train in characterizing the actual state of vehicle, laying a foundation for vehicle stability control.

Key words. Semi-trailer train, parameter identification, genetic algorithm, l-m algorithm..

1. Introduction

Semi-trailer train is widely used in the road transport industry because of its high efficiency, low cost, practical and many other advantages. But because of their structural characteristics, poor stability, easy to occur in the driving vibration, rollover and folding and other dangerous accidents, resulting in serious traffic accidents or property damage[1]. It is of great significance to study the stability control method of semi-trailer train to improve driving stability and safety. The stability control of the vehicle depends on the establishment of the vehicle model and the determination

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of the key parameter values of the model[2].

Mai et al.[3] has carried on the calibration of several key parameters under lateral acceleration, but can not realize the real-time change of the model parameters with the vehicle state change. Yu et al.[4] have identified the key parameters of different steering wheel and vehicle speed, but it is difficult to ensure the accuracy of the key parameters of the model by using trial and error method. Baffet et al.[5] identifies the sideslip angle and the wheel cornering stiffness of the tire through the Extended Kalman Filter method, but there are related problems such as parameter noise variance and unknown noise variance in actual system identification.

At present, the algorithms used in parameter identification are as follows: Least squares method, Maximum likelihood method, Gradient correction method, Neural network and genetic algorithm. Least square method has the problem of data saturation, So that the identification parameters are easily trapped in the local optimal solution; The maximum likelihood method must write the conditional probability density function of the output; Gradient correction method requires the existence of gradient of the optimized object; Genetic algorithm has the disadvantage of optimizing too many parameters and poor accuracy at the same time. As the semi-trailer train mathematical model of the structure is more complex and more difficult to identify the parameters, If an algorithm is used to identify multiple parameters at the same time, Because of the limitations of the algorithm itself can not fully meet the accuracy of parameter identification requirements. Therefore, the above identification method can not fully meet the requirements of the accuracy of parameter identification[6].

In this paper, combined with the advantages of genetic algorithm and L-M optimization algorithm, The model parameters are identified by the combination of two algorithms, and compared with the simulation data of TruckSim software. The combination of genetic algorithm and L-M optimization algorithm inherits the advantages of global optimization of genetic algorithm, and overcome the shortcomings of the genetic algorithm while optimizing multiple parameters is not accurate enough, can successfully identify the key parameters of the established mathematical model with high accuracy.

2. Dynamic mathematical model

2.1. Establishment of Motion Differential Equation

Using the vehicle moving coordinate system, The coordinate system is a rectangular coordinate system which is often used to discuss vehicle handling stability. Semi-trailer train yaw, lateral movement force diagram shown in Figure 1, its roll movement force diagram shown in Figure2.

According to the force of the semi-trailer train in the direction of yaw, lateral and roll, the inertia force of the vehicle along the Y-axis, the inertia moment of the vehicle to the Z-axis and the inertia moment of the suspension mass to the X-axis are analyzed. The differential equation of motion of three degrees of freedom of tractor and trailer is established.

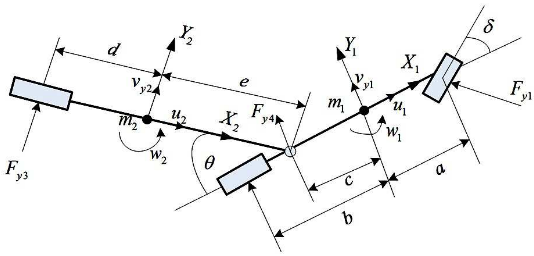

Fig. 1. The sketch map of yaw and lateral movement of the semi-trailer train

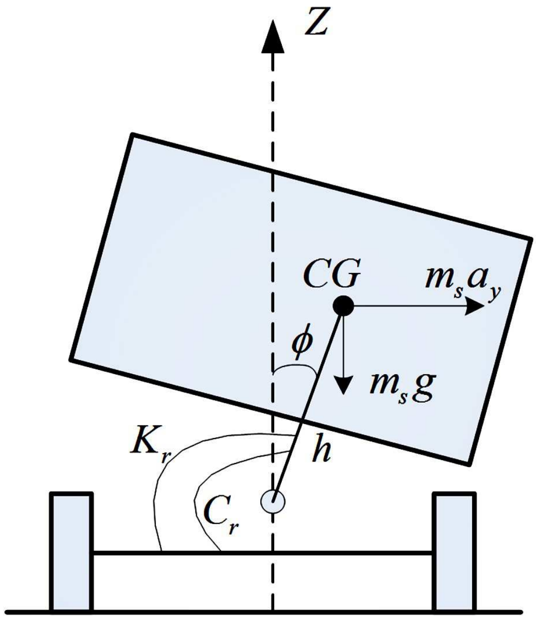

Fig. 2. The sketch map of roll movement of semi-trailer train

Traction Motion Differential Equation is established:

$$\begin{cases} \sum F_{Y1} = m_{1} u(\dot{\beta}_1 + w_1) - m_{1s} h_{1} \ddot{\phi}_1 \\ \sum M_{Z1} = I_{1zz} \dot{w}_1 - I_{1xz} \ddot{\phi}_1 \\ \sum M_{X1} = (I_{1xx} + m_{1s} h_1^2) \ddot{\phi}_1 - I_{1xz} \dot{w}_1 \end{cases} \tag{1}$$

Trailer Motion Differential Equation:

$$\begin{cases} \sum F_{Y2} = m_{2}u(\dot{\beta}_2 + w_{1}) - m_{2s}h_2 \ddot{\phi}_2 \\ \sum M_{Z2} = I_{2zz}\dot{w}_2 - I_{2xz}\ddot{\phi}_2 \\ \sum M_{X2} = (I_{2xx} + m_{2s}h_2^2)\ddot{\phi}_2 - I_{2xz}\dot{w}_2 \end{cases} \tag{2}$$

2.2. Force analysis of tire

In the force analysis of the tire, assuming that the front and rear wheels of the tire are concentrated at the midpoint of the front and rear axles respectively, The equivalent tire model of semi-trailer train is shown in Figure 3.

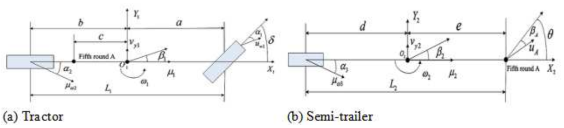

Fig. 3. The equivalent tire model of semi-trailer train

Using the linear tire model, get the equation of the side force of each axle of the tire:

$$\begin{cases} F_{y1} = k_1(\beta_1 + \frac{aw_1}{u} - \delta) \\ F_{y2} = k_2(\beta_1 - \frac{bw_1}{u}) \\ F_{y3} = k_3(\beta_2 - \frac{dw_2}{u}) \end{cases} \tag{3}$$

2.3. Establishment of Motion Differential Equation

Equation of total external force of tractor:

$$\begin{cases} \sum F_{Y1} = F_{y\,1} + F_{y\,2} + F_{y\,4} \\ \sum M_{Z1} = F_{y\,1}a - F_{y\,2}b - F_{y\,4}c \\ \sum M_{X1} = m_{1s}gh_1\phi_1 + m_{1s}[u_1(\dot{\beta}_1 + w_1) - h_1\ddot{\phi}_1]h_1 + k_{12}(\phi_2 - \phi_1) - F_{y4}h_{1c} \end{cases} \tag{4}$$

Equation of total external force of trailer:

$$\begin{cases} \sum F_{Y2} = F_{y3} - F_{y4}\cos\theta \\ \sum M_{Z2} = -F_{y3}d - eF_{y4}\cos\theta \\ \sum M_{X2} = m_{2s}gh_2\phi_2 + m_{2s}[u_2(\dot{\beta}_2 + w_2) - h_2\ddot{\phi}_2]h_2 - k_{12}(\phi_2 - \phi_1) + F_{y4}h_{2c} \end{cases} \tag{5}$$

2.4. Force balance equation of semi-trailer train

According to the analysis of 1.1, 1.2 and 1.3, the force balance equation of semi-trailer trains can be listed.

Will be equation (3)to equation (3) ,and the combination of equation (1)can be

obtained the Force balance equation of tractor, which show in equation (6).
Force balance equation of tractor:

$$\rho[v_x\frac{\partial(c_vT)}{\partial\theta}+v_y\frac{\partial(c_vT)}{\partial y}+v_y\frac{\partial(c_vT)}{\partial z}]=\mu((\frac{\partial v_x}{\partial y})^2+(\frac{\partial v_z}{\partial y})^2) \tag{6}$$

Assuming that the hinge angleθ is small, thereforecos$\,\theta\approx 1$, will be equation (3) to equation (5),and the combination of equation (2) can be obtained the Force balance equation of trailer, which show in equation (7).
Force balance equation of trailer:

$$\rho[\frac{hU}{2}-\frac{h^3}{12\mu}\frac{\partial p}{\partial x})\frac{\partial(c_vT)}{\partial x}+(-\frac{h^3}{12\mu}\frac{\partial p}{\partial x})\frac{\partial(c_vT)}{\partial z}]=\frac{\mu U^2}{h}+\frac{h^3}{12\mu}[(\frac{\partial p}{\partial x})^2+(\frac{\partial p}{\partial z})^2] \tag{7}$$

Traction and semi-trailer kinematic constraint equation:

$$\dot{\beta}_2-\dot{\beta}_1-\frac{h_{1c}}{u_1}\ddot{\phi}_1+\frac{h_{2c}}{u_2}\ddot{\phi}_2-\frac{c}{u_1}\dot{w}_1-\frac{e}{u_2}\dot{w}_2+w_1-w_2=0 \tag{8}$$

Joint equation (6), equation (7) and equation (8), eliminateF_{y4}, finishing the semi-trailer train dynamic mathematical model of the matrix form:

$$T\dot{X}=MX+KU \tag{9}$$

Among them,$X=[\beta_1,\omega_1,\varphi_1,\dot{\varphi}_1,\beta_2,\omega_2,\varphi_2,\dot{\varphi}_2]^T$

$$U=\delta\dot{X}=\left[\dot{\beta}_1,\dot{\omega}_1,\dot{\varphi}_1,\ddot{\varphi}_1,\dot{\beta}_2,\dot{\omega}_2,\dot{\varphi}_2,\ddot{\varphi}_2\right]^T$$

$$T=\begin{bmatrix} m_1u_1c & I_{1zz} & 0 & -m_{1s}h_1c & 0 & 0 & 0 & 0 \\ m_1u_1h_{1c} & -I_{1xz} & 2m_{1s}h_1^2 & 0 & 0 & 0 & 0 & \\ m_1u_1 & 0 & 0 & -m_{1s}h_1 & m_2u_2 & 0 & 0 & -m_{2s}h_2 \\ 0 & 0 & 0 & m_2u_2e & -I_{2zz} & 0 & -m_{2s}h_2e & \\ 0 & 0 & 0 & 0 & m_2u_2h_{2c} & -I_{2xz} & 0 & 2m_{2s}h_2^2 \\ 1 & -\frac{c}{u_1} & 0 & -\frac{h_{1c}}{u_1} & -1 & -\frac{e}{u_2} & 0 & \frac{h_{2c}}{u_2} \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \end{bmatrix}$$

$$M = \begin{bmatrix} (c+a)k_1 & \frac{a(c+a)k_1}{u_1} & 0 & 0 & 0 & 0 & 0 & 0 \\ k_1h_{1c}+k_2h_{1c} & \frac{ah_{1c}k_1}{u_1} & m_{1s}gh_1 & -c_{r1} & 0 & 0 & 0 & 0 \\ k_1+k_2 & \frac{k_1a}{u_1} & 0 & 0 & k_3 & -\frac{k_3d}{u_2} & 0 & 0 \\ 0 & 0 & 0 & 0 & k_3(e+d) & \frac{(e+d)dk_3}{u_2} & 0 & 0 \\ 0 & 0 & k_{12} & 0 & k_3eh_2 & m_{2s}h_2u_2 & m_{2s}gh_2 & \\ 0 & -1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$K = [-\ (c+a)k_1 \quad -k_1h_{1\mathrm{c}} \quad k_1\ 0 \quad 0 \quad 0 \quad 0 \quad 0]^T$$

Order$A = T^{-1}M, B = T^{-1}K$,The formula (9) can be rewritten into a state space standard form:

$$\dot{X} = AX + BU \tag{10}$$

All of the above formula and figure in the meaning of the symbols are given in Table 1.

Table 1.Error function symbol meaning.

Symbol	Meaning
a	Tractor center of mass to the front axle distance of the tractor
b	Tractor center of mass to the rear axle distance of the tractor
c	Tractor center of mass to fifth axis distance
e	Trailer center of mass to fifth axis distance
d	Trailer center of mass to the trailer axle distance
g	Gravity acceleration
$m_1 \quad m_2$	Tractor, Trailer quality
$u_1 \quad u_2$	Tractor, Trailer forward speed
$\omega_1 \quad \omega_2$	Yaw rate of the tractor, trailer around the Z axis
θ	Tractor and trailer hinge angle
F_{y1}	Tractor front axle side force
F_{y2}	Tractor rear axle side force
F_{y3}	Trailer axle side force
F_{y4}	The lateral interaction force at the hinge point
δ	Front wheel angle
$\beta_1 \quad \beta_2$	Sideslip angle of center of mass of tractor and trailer
$\dot{\beta}_1 \quad \dot{\beta}_2$	Sideslip angle speed of center of mass of tractor and trailer
$\omega_1 \quad \omega_2$	Yaw rate of tractor and trailer
$\dot{w}_1 \quad \dot{w}_2$	Yaw acceleration of tractor and trailer
$\phi_1 \quad \phi_2$	Roll angle of tractor and trailer
$\dot{\phi}_1 \quad \dot{\phi}_2$	Roll angle speed of tractor and trailer
$\ddot{\phi}_1 \quad \ddot{\phi}_2$	Roll angle acceleration of tractor and trailer
$m_{1s} \quad m_{2s}$	Sprung mass of tractor and trailer
$h_1 \quad h_2$	Tractor, trailer center of mass to their respective roll axis distance
$h_{1c} \quad h_{2c}$	Tractor, trailer the fifth round of the height from the ground
$I_{1zz} \quad I_{2zz}$	Tractor, trailer around the Z axis of inertia
$I_{1xx} \quad I_{2xx}$	Tractor, trailer around the X axis of inertia

3. Paramater identification

3.1. Trucksim Vehicle model

TruckSim is a professional vehicle dynamics simulation software, used to simulate the vehicle's power, economy, stability, ride comfort and braking. It can dynamically simulate the various experiments of the car, has been used by many domestic and foreign manufacturers of automobile manufacturers and materials parts, has become the automotive industry enjoyed a high reputation of the standard software. The use of TruckSim software to evaluate the overall performance of the vehicle is increasing. Taking a three axle semitrailer train as an example, as the semi-trailer train test is difficult and some tests are dangerous, especially in vehicle stability, so the use of TruckSim vehicle model simulation test data to replace the real vehicle test data.

TruckSim vehicle model shown in Figure. 4, The model inputs the steering wheel angleδdata, output for the$\beta_1, \omega_1, \phi_1, \dot{\phi}_1, \beta_2, \omega_2, \phi_2, \dot{\phi}_2$ total of eight sets of simulation test data.

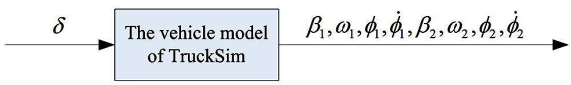

Fig. 4. The vehicle model of TruckSim

3.2. Vehicle model

Figure.5 is based on the equation (10) established semi-trailer train mathematical model. the model input for the front wheel angleδ_f(which is obtained by converting the steering wheel angleδdata from the TruckSim vehicle model input at Figure.4), the output data is the same as the TruckSim vehicle model.

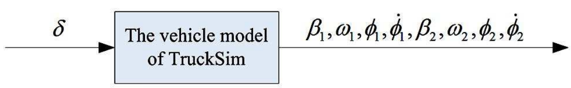

Fig. 5. Mathematic model of semi-trailer train

In the model, the parameters of the TruckSim vehicle model are used except for the eight parameters Tractor front axle lateral stiffnessk_1, Tractor rear axle lateral stiffnessk_2, Tractor roll stiffnessk_{r1},Tractor roll dampingc_{r1}, Trailer axle lateral stiffnessk_3, Trailer roll stiffnessk_{r2}, Trailer roll damping$c_{r2}$and Fifth wheel roll stiffnessk_{12}which have not been identified.

3.3. Step identification method selections

The genetic algorithm does not depend on the initial value of the parameters and makes use of the population rather than the individual to search, and gradually achieve the global optimum. And genetic algorithm can simultaneously optimize multiple parameters. But the accuracy in the optimization parameters at the same time it will become worse, cause certain error; The L-M algorithm has faster convergence speed and optimization accuracy but the dependence on initial parameters; the least squares method is the saturated phenomenon of data, easy to fall into local optimal solution. In order to overcome the shortcomings of the genetic algorithm, a step-by-step identification method combining genetic algorithm and L-M optimization algorithm is proposed. First based on genetic algorithm for the initial identification, and then the traditional L-M optimization algorithm for optimization. The result of a genetic algorithm is the initial value of L-M algorithm, which can solve the problem that the traditional method is too dependent on the initial value.

3.4. Initial identification based on genetic algorithm

The main feature of a genetic algorithm that has the ability of global optimization, the genetic algorithm selection, retaining the useful "genetic information", application of a single point and multi-point uniform and arithmetic crossover method to guarantee the ability of global optimization. The mathematical function of the optimization problem is:

$$\begin{array}{ll} find & X=[X_1,X_2,\cdots,X_n]^T \\ \min & F\left(X\right)=\min f\left(X\right) \\ s.t & g_j\left(X\right)\leq 0\left(j=1,2,\cdots,p\right) \\ & h_k\left(X\right)\leq 0\left(k=1,2,\cdots,p\right) \\ & X^L\leq X\leq X^U \end{array} \tag{11}$$

Formula (11),$X=[x_1,x_2,\cdots,x_n]^T$is the design variables of the objective function of$F(X)=\min f(x)$,$g_j(x)\leq 0$is the inequality constraints of design variables,$h_k(x)=0$is constrained to design variables,X^LandX^Urespectively, the upper and lower bounds of design variables.

3.5. Re-identification Based on L-M Optimization Algorithm

L-M identification using Matlab software Control Estimation Manager toolbox to achieve. The parameter values obtained by genetic algorithm as the initial value of L-M optimization algorithm, Based on the principle of L-M algorithm, The parameters of the model are optimized and calibrated by iterative operation, a set of parameter values which can make the error between the calculated data of the model and the TruckSim test data E (see 12) get the minimum value.

Error E:

$$
\begin{aligned}
E =&\frac{1}{2}\sum_{i=1}^{n}[\bar{\beta}_1(i)-\beta_1^*(i)]^2+\frac{1}{2}\sum_{i=1}^{n}[\bar{w}_1(i)-w_1^*(i)]^2+\frac{1}{2}\sum_{i=1}^{n}[\bar{\phi}_1(i)-\phi_1^*(i)]^2+\\
&\frac{1}{2}\sum_{i=1}^{n}[\bar{\dot{\phi}}_1(i)-\dot{\phi}_1^*(i)]^2+\frac{1}{2}\sum_{i=1}^{n}[\bar{\beta}_2(i)-\beta_2^*(i)]^2+\\
&\frac{1}{2}\sum_{i=1}^{n}[\bar{w}_2(i)-w_2^*(i)]^2+\frac{1}{2}\sum_{i=1}^{n}[\bar{\phi}_2(i)-\phi_2^*(i)]^2+\frac{1}{2}\sum_{i=1}^{n}[\bar{\dot{\phi}}_2(i)-\dot{\phi}_2^*(i)]^2
\end{aligned}
\tag{12}
$$

3.6. Parameter identification results

The constant speed test with the steering wheel angle as input is an important objective test of vehicle stability, and it is also an important identification condition for linear vehicle model identification. Therefore, design identification working conditions: The vehicle speed is 70km/h, and the steering wheel angle is 90-degree angle step, and the input of the steering wheel angle is shown in figure 7. The truckSim vehicle simulation test data under this condition is used as the database for identification.

The key parameters of the initial identification of the genetic algorithm are shown in Table 2. The identification of the key parameters of the L-M optimization algorithm is shown in Table 3.

Table 2. Identify results of the genetic algorithm.

Parameter	Identification value	Parameter	Identification value
$k_1\,(N/rad)$	-2.4315×10^5	$k_{r2}\,(N\cdot m/rad)$	7.2358×10^5
$k_2\,(N/rad)$	-4.9675×10^5	$c_{r1}\,(N\cdot m\cdot s/rad)$	6.3839×10^5
$k_3\,(N/rad)$	-2.9003×10^5	$c_{r2}\,(N\cdot m\cdot s/rad)$	1.3164×10^5
$k_{r1}\,(N\cdot m/rad)$	2.2482×10^5	$k_{12}\,(N\cdot m/rad)$	1.8217×10^5

Table 3.Identify results of L-M optimization algorithm.

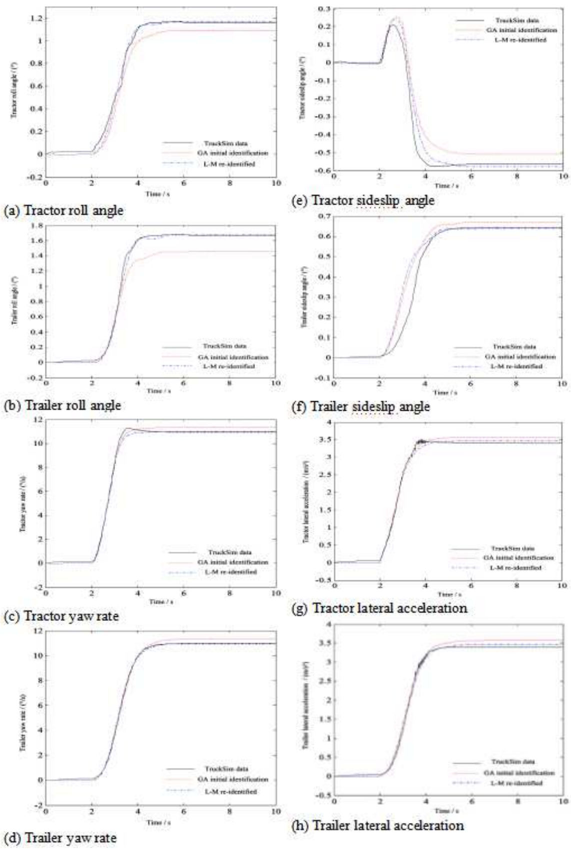

Fig. 6. The steering wheel angle input curve of angular step condition

Parameter	Identification value	Parameter	Identification value
$k_1\,(N/rad)$	-2.4159×10^5	$k_{r2}\,(N \cdot m/rad)$	7.5189×10^5
$k_2\,(N/rad)$	-4.9102×10^5	$c_{r1}\,(N \cdot m \cdot s/rad)$	6.3237×10^5
$k_3\,(N/rad)$	-3.0147×10^5	$c_{r2}\,(N \cdot m \cdot s/rad)$	1.3136×10^5
$k_{r1}\,(N \cdot m/rad)$	2.2973×10^5	$k_{12}\,(N \cdot m/rad)$	1.8633×10^5

4. Identification results analysis

In the angular step identification conditions, the identification results obtained by two identification as shown in Table 2, Table 3. The accuracy of parameter identification is evaluated by quantitative analysis and comparative analysis of the results.

4.1. Quantitative analysis

According to the identification data, the quantitative analysis method is used to evaluate the accuracy of parameter identification. The identification of eight parameters results back into the model calculation results and TruckSim data were compared, using residual index to evaluate MSE, its specific meaning is: the square root of the relative error between the model output data and TruckSim simulation data, the smaller the value of the model, the smaller the error between the model data and TruckSim data, the more accurate identification results.

MSE indicators are defined as equation (13):

$$MSE = \sqrt{\frac{\sum_{i=1}^{n}\left[(\bar{\beta}_1 - \beta_1^*)^2 + (\bar{w}_1 - w_1^*)^2 + (\bar{\phi}_1 - \phi_1^*)^2 + (\bar{\dot{\phi}}_1 - \dot{\phi}_1^*)^2 + (\bar{\beta}_2 - \beta_2^*)^2\right]}{\sum_{i=1}^{n}\left[(\beta_1^*)^2 + (w_1^*)^2 + (\phi_1^*)^2 + (\dot{\phi}_1^*)^2 + (\dot{\phi}_2^*)^2\right]}} \tag{13}$$

It can be concluded that the MSE value of the initial identification based on genetic algorithm is 0.1185, and the MSE value based on the L-M optimization algorithm is 0.0332.The MSE value of the two identification is small, but the L-M algorithm is more small, which shows that the obtained parameters are more accurate. The results show that the accuracy of the identification results obtained by the two-step identification method is higher.

4.2. Comparative analysis

In order to test the identification results more intuitive quality, using comparative method graph model and TruckSim data, the genetic algorithm identification values (Table 2) and the L-M to identify the values (Table 3) respectively, and run into the model, the two model simulation results and the simulation results with TruckSim data were compared, as shown in Figure 8 shown.

Figure 8 is the comparison of the results of GA method and L-M method under the condition of 90 degree angle step steering. Can be seen from the comparison of the angle of inclination in figure (a) and figure (b), The steady state values of the tractor side slope and the trailer side angle of the initial identification of the GA method are 0.1 and 0.2 degrees, respectively, In contrast, after the L-M method to re-identify the basic error, indicating that the L-M method to re-identify the effect better. In (c) and (d), the L-M method re-identifies the overall fitting effect better than the first recognition of the GA method; After the initial identification of the GA method, the response of the yaw rate in the steady state is different from that of the TruckSim data. After the L-M method, the yaw rate response curve of the model is consistent with the TruckSim data, which reduces the steady-state error. It can be seen from the contrast of the center of mass in the graphs (e) and (f) that the LM algorithm re-identifies the post-fitting effect better, The overall trend of the center-of-mass curve of the tractor and the trailer is basically the same as

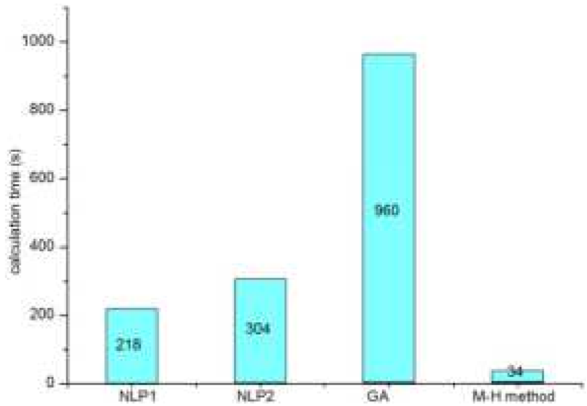

Fig. 7. Comparison of the GA and L-M identification results under the condition of 90deg angle step

the amplitude. From the comparison of the lateral acceleration of the graph (g) and (h), it can be seen that the steady-state value is closer to the TruckSim data after the L-M method is re-identified, the fitting effect is better, Indicating that the L-M method is re-identified to obtain a more accurate identification value.

In summary, under the condition of 90 degree angle step steering, on the basis of genetic algorithm, the L-M algorithm can be used to identify the more accurate parameter values, so that the model data can be in good agreement with the TruckSim data. The results show that the accurate parameter values can be identified by the step by step identification method, and the output data of the semi-trailer train model can be in good agreement with the TruckSim simulation data.

5. Concluding remarks

Based on the principle of vehicle dynamics, the dynamic mathematical model of semi-trailer train is established and transformed into the form of a standard state space equation. In order to solve the problem that the parameters of semi-trailer train model are difficult to identify, a new method based on genetic algorithm and L-M algorithm is proposed. Based on the TruckSim data, eight key parameters which are difficult to be determined in the model are obtained under the condition of 90 degree angle step. By comparing with the TrucSim simulation data, the mathematical model of the calculated data can be well fitted with it to show that:

1) Under the step turning condition of 90 degree angle, On the basis of genetic algorithm identification, the more accurate parameter values can be obtained by L-M algorithm reidentification, so that the model data can be better consistent with the TrucSim data.

2) The output data of the constructed mathematical model is in good agreement with the TrucSim simulation data, the step-by-step identification can be used to obtain accurate parameter values, So that the mathematical model can be more accurately describe the actual vehicle movement characteristics, which will lay a

good foundation for the research of rollover control system for semi-trailer.

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