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Study on the prediction method of Off-Road Speed of Tracked Vehicles on Uneven Road

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ABSTRACT: Based on the multi-body dynamics model of tracked vehicle which has been tested and verified, the mathematical relationship between road roughness and speed is obtained by using the method of experiment design, approximation model and goal seeking, and the calculation method of off-road speed under the condition of random rough pavement is given. The method is used to calculate the test ground, and the results show that the model can reflect the impact of road roughness on the vehicle speed, and provide an effective quantitative means for vehicle mobility prediction.

KEYWORDS: Mobility, multi-body dynamics, approximate model, off-road speed

1. Introduction

With the continuous deepening of military revolution, the mobility of tracked vehicles has been paid more and more attention [1]. The influence of terrain factors on the mobility of tracked vehicles is mainly due to the two aspects of road roughness and firmness. The vehicle model established in China's mobility study is quite different from the three-dimensional entity model, and the credibility of the model has not been tested. Moreover, the method of calculating maximum vehicle speed has limitations, which can not directly reflect the relationship between road roughness and vehicle speed. It is difficult to get the off-road speed of vehicles under uneven road quickly.

In order to solve the above problems, a method for calculating average speed of vehicle off-road under uneven road is proposed by combining the dynamic modeling, experimental design, approximate model and target optimization in this paper This method reflects the real vehicle vibration more effectively, and can effectively calculate the average off-road speed of vehicles passing through different uneven roads, which provides an effective technical way for vehicle mobility prediction.

2. Multi-body dynamic modeling of tracked vehicle

When the tracked vehicle is running on the rough road, the bumping degree of the vehicle is the main factor that limits the vehicle speed [2]. The maximum off-road speed is usually determined by the vibration response of the vehicle. In order to accurately reflect the vibration characteristics of tracked vehicles passing on uneven road, a multi rigid body model of vehicle chassis system is established. Based on a given vibration response evaluation index, the accuracy of the model is verified by real vehicle test.

2.1 Dynamic model of tracked vehicle chassis system

Taking a high-speed tracked vehicle as an example, when establishing the chassis system model, all components are assumed as rigid bodies, while ignoring the factors that have little influence on vehicle vibration response. In the model, the upper part, the power transmission system and the car body are combined as one rigid body. The action system is simplified as a driving wheel, a loading wheel, a supporting wheel, an inducer, a track tensioner, a track and an elastic damping element [3].

Based on Eulerian four dimensional generalized coordinates, combined with vehicle design parameters, the theory of multi-body system dynamics is used to build tracked vehicle chassis system dynamics model in ADAMS/ATV, as shown in Fig. 1.

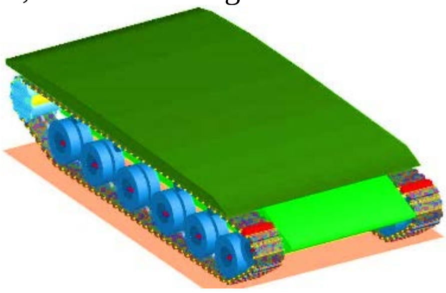


Fig. 1 Dynamic model of tracked vehicle chassis system

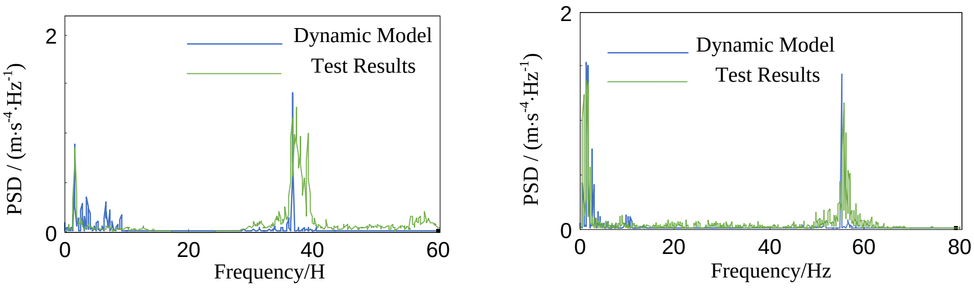
2.2 Vibration response evaluation index

Under the condition of satisfying the power and transmission performance, the maximum endurance of the vehicle on the uneven road is determined by the endurance limit of the vibration response of the occupant and car body to the tracked vehicle [4]. Starting from three aspects of ride comfort, human body endurance and suspension reliability, three kinds of vibration response evaluation indicators are summarized, and the threshold value is used to determine whether the vehicle speed reaches the maximum.

The ride comfort requires that the total root mean square of vibration acceleration weighted in the seat seat of the crew is $a_w \le 1 m \cdot s^{-2}$. The root mean square value of the limit vertical weighted acceleration corresponding to the absorption power standard is 0.69 $m \cdot s^{-2}$. The threshold value of the root mean square value of the first load wheel is 0.12 to avoid the hanging breakdown.

2.3 Test verification

The credibility of the dynamic model is verified by a real vehicle test. The test personnel selected 3 gears, 4 gears to collect the vibration signals of the key parts of the vehicle, respectively. The power spectral density curves of the vertical acceleration signals of the driver's seat in the simulation model and the real vehicle test are compared with that shown in Fig. 2. The curve shows that the simulation results are in good agreement with the experimental results, and the main peak frequency is very close, with high consistency.



（a）3gears （b）4gears

Fig. 2 Comparison of simulation and test data

In order to verify whether the simulation model can better reflect the vibration response of the real vehicle, the evaluation index of the vibration response in the 1.2 section is calculated, and the comparison results are shown in Table 1.

Table 1 Comparison of evaluation index of vibration response of tracked vehicle system

Evaluation index of vibration response	Working condition	Dynamic Model	Test Results	Error
Total weighted acceleration RMS of driver's seat	4gears	0.910	0.101	9.38%
Vertical weighted acceleration RMS of driver's seat	4gears	0.605	0.671	9.84%
Moving stroke RMS of first load wheel	4gears	0.086	0.078	9.30%

The data in the table show that the vibration response of the system is quite different from the test results, and the error is less than 10%. By comparing the simulation results with the real vehicle test data, it is shown that the dynamic model of tracked vehicle can reflect the real vehicle's vibration response characteristics comprehensively and accurately, and the given vibration response evaluation index can be used for subsequent calculation.

2 Prediction of maximum driving speed on uneven road

2.1 Test design and simulation calculation

Taking the road roughness $Gq(n)$ and vehicle speed v as design variables, the approximate model is used to replace the original complex model, which can greatly reduce the number of simulation and intuitively describe the mathematical relationship between road roughness and vehicle speed. By using optimal Latin hypercube design in $Gq(n)$ and v range from 20 samples, Fig. 3 shows the sample point distribution diagram.

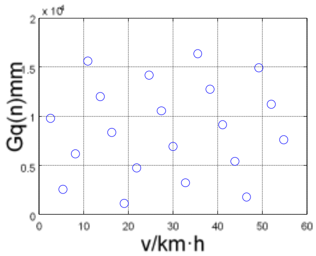


Fig. 3 Optimal Latin hypercube design sample

By 20 groups of simulation result, the driver's seat 3 axial vibration acceleration and wheel travel of 4 output response is given. The total weighted acceleration RMS of driver's seat, vertical root weighted acceleration RMS of driver's seat and the first wheel load RMS are processed, which are instead of the evaluation index 1, 2, 3, 4 in the post.

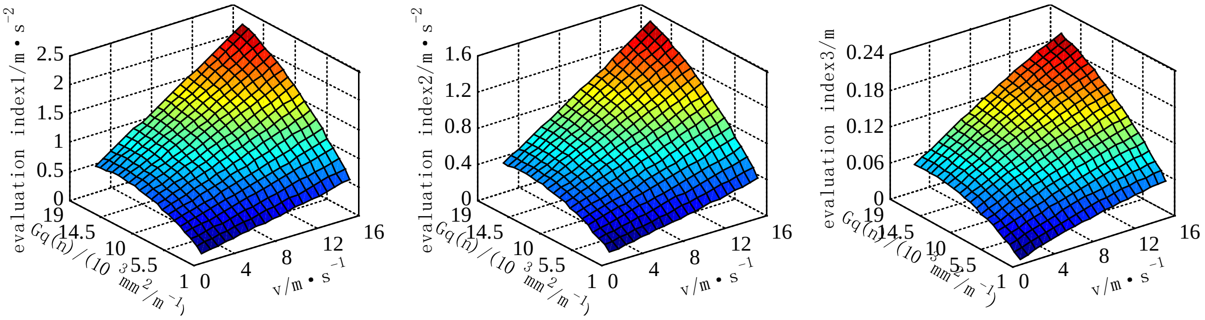
3.2 approximation model

The two order polynomial response surface model is used in engineering to fit the design variables and the response values with nonlinear relation [5]. The expression is

$$y_d = \alpha_0 + \sum_{i=1}^{n} \alpha_i x_i + \sum_{ij(i<j)}^{n} \alpha_{ij} x_i x_j + \sum_{i=1}^{n} \alpha_{ii} x_i^2 \qquad (1)$$

Here, y_d is response valve， x_i , x_j are design variables， n is the number of design variables， α_0, α_i , α_{ij} , α_{ii} are the coefficients of polynomial。

Taking the evaluation index as the output response and taking the speed and the road roughness as the design variables, the polynomial response surface model is set up as shown in Fig. 4.



a) b) c)

Fig. 4 Results of approximation model

The graph shows that the vibration response of the vehicle is becoming more and more intense with the increase of speed or the increase of the roughness of the road.

The R2 test method is used to test the accuracy of the model. R2 is the complex correlation coefficient， which represents the proximity of the predicted value to the true value. It can be seen in Table 2 that the complex correlation coefficients of the objective function are more than 0.9, which satisfies the requirement of precision.

Table 2 Precision test of polynomial response surface

Vibration response	Evaluation index1	Evaluation index2	Evaluation index3
R^2	0.9858	0.9671	0.9547

3.4 Maximum off-road speed calculation

The computation process of solving the maximum off-road speed can be simplified as implicit constraint optimization problem. The global optimal solution of the objective function speed is solved by taking the road roughness coefficient as the variable and the vibration response quantity as the constraint. Combining the threshold value of the evaluation index of the vibration response, the expressions of the maximum off-road speed are

$$\begin{array}{ll} \mathit{Maximum} & v_i(f), \\ \mathit{Subject\ to} & y_{d_1}[v, G_q(n)] \le 1.2, \\ & y_{d_2}[v, G_q(n)] \le 0.69, \\ & y_{d_3}[v, G_q(n)] \le 0.12, \\ & y_{d_4}[v, G_q(n)] \le 0.75, \\ & G_q(n)^{(L)} < G_q(n) < G_q(n)^{(U)}, \end{array} \quad (2)$$

The calculation shows that the maximum off-road speed of vehicles on different road surface roughness is drawn within a certain range.

Taking the mean of road roughness G=7680mm^2/m^{-1} as an example, the relationship between vehicle speed and three kinds of vibration responses is obtained by substituting the approximate model. As shown in Fig. 5, the maximum speed of v=6.23m/s is calculated from the formula (2).

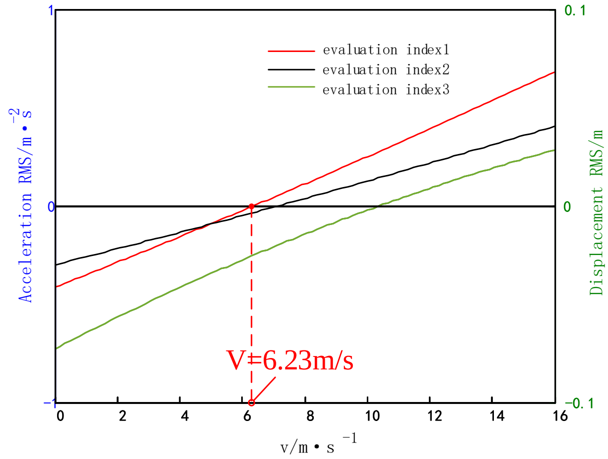


Fig. 5 Results of maximum off-road speed

4. Conclusion

A new idea of solving the off-road speed of tracked vehicle on uneven road is given by using the technology of simulation modeling, experiment design, approximate modeling and target optimization. The conclusions are as follows:

1. The multi rigid body model and random road digital model of tracked vehicle chassis system are established. Vibration response evaluation index is summarized from the aspects of ride comfort, human body endurance and suspension reliability. And the credibility of the model is verified by comparing the simulation results with the real vehicle test.

2. Based on the multi-body dynamics simulation model, combined with the experimental design method of the simulation, the approximate model between the road roughness coefficient and the speed of the two design variables and vibration response, fitting the road roughness coefficient and the mathematical relationship between the speed, puts forward the calculation method of road vehicle off-road speed. This method can quickly predict the maximum off-road speed of the vehicle in the uneven pavement, and provides a positive quantitative analysis approach for the research of mobility.

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