Simulation of the Tracked Vehicle Climbing Over Vertical Wall

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Abstract. Based on theory of multi-body system dynamics, in the ADAMS virtual environment, a type of tank vehicle is presented as the research object, the simulation tests of the tracked vehicle on part of working condition of typical driving dynamics characteristics on cross-country mobility were obtained. The simulation of climbing over vertical wall of the tracked vehicles was obtained. Through the dynamics analysis and simulation of the tracked vehicle, the theoretical guidance of the tracked vehicle on maneuverability evaluation and optimization of the driving device are provided.

Introduction

The dynamics of tracked vehicle involve ground vehicles principle, multi-body system dynamics, virtual prototype technology, computer numerical calculation, and other fields. With the development of high-speed military tracked vehicle, the requirement for enhancing mobility enhances. Track and suspension system compose a dynamic correlation system, constitute the movement interface of body and ground. The design of the mobility system is based on the specific requirements of vehicle performance and provisions of all terrain using ability, and the damping function.

In the real vehicle experiment of climbing over vertical wall of real vehicle experiments, there are the problems of falling or overturning, thus the security risk to crew members is posed. The test times can be reduced through the simulation analysis, the test security can be improved, and the related simulation analysis results can also be used for theory reference to the real vehicle driving. Operations on vehicle performance and the ability to Special request for survive makes maneuverability problem of military tracked vehicle further complicated, thus the new requirements for tracked vehicle dynamics analysis are put forward. Then not only the vehicle maneuverability assurance is improved, but also the handing stability and the ride comfort of the tracked vehicle are improved, and the parts attrition of the tracked vehicle are greatly reduced, the cost of the vehicle maintenance is saved. Therefore, the research on tracked vehicle system dynamics has important engineering practical significance.

Modeling Principle of Multi-body Principle

The equilibrium equation for multi-body system dynamics of tracked vehicle¹ is deduced from the establishment of generalized coordinates and virtual work principle. The virtual work of internal force system is equal to the sum of virtual work of the system by external forces and constraint reaction forces.

$$\delta W_{f,d} = \delta W_{e,d} + \delta W_{c,d}$$

The virtual work for the external force on the rigid body is

$$\delta W_{e,d} = Q_{e,d}^T \delta q_i$$

Where $Q_{e,d}^T$ is the overall external force vector working in a generalized coordinates.
Equation (1.2) is a generalized coordinates role in the overall external force vector. The second item of equation 1 type is the role of the rigid constraints reaction do virtual work. The second item of equation 1 is the virtual work of constraining force on the rigid body

\[ \delta W_{c,i} = Q_{c,i}^T \delta q_i \]

(3)

\[ Q_{c,i}^T \] is defined as the total reaction forces of constraints vector in the generalized coordinate \( q_i \).

The virtual work done by the internal force can be expressed as:

\[ \delta W_{i,i} = \int \rho_i \delta r_i \delta r_i dV_i \]

(4)

where \( \rho_i \) and \( V_i \) is defined as the density and volume of object I, respectively. The relative position of the general coordinates to arbitrary point of object I are expressed as:

\[ r_i = R_i + A_i \bar{u}_i \]

the rotation matrix for object i in the rotation Angle \( \theta_i \) is expressed as:

\[ A_i = \begin{bmatrix} \cos \theta_i & -\sin \theta_i \\ \sin \theta_i & \cos \theta_i \end{bmatrix} \]

The virtual work done by internal force of the object i can be expressed as:

\[ \delta W_{i,i} = [M_i \ddot{q}_i - Q_{r,i}]^T \delta q_i \]

Where \( Q_{r,i} \) is the inertial centrifugal force vector. Then the followings can be obtained;

\[ [M_i \ddot{q}_i - Q_{r,i} - Q_{c,i}]^T \delta q_i = 0 \]

Then the system equation is

\[ M \ddot{q} + C_q^T \lambda = Q_e \]

The system equation contains( 3 a + b) unknown quantities and 3 a balance equations. A indicates the number of objects of the system, b is the number of independent constraint equations. And the systematic constraint equation can be expressed as:

The derivative equation is

\[ C_q \dddot{q} = Q_d = -\left(C_q \dddot{q}_q \right) \dot{q} - 2C_q \dddot{q} - C_n \]

The multi-body dynamics equation of three dimensional tracked vehicle system is expressed as:

\[ \begin{bmatrix} M & C_q^T \\ C_q & 0 \end{bmatrix} \begin{bmatrix} \ddot{q} \\ \lambda \end{bmatrix} = \begin{bmatrix} Q_e \\ Q_d \end{bmatrix} \]

Using multi-body dynamics method for tracked vehicle system modelling, the most complex part is the description of the modelling and connection of track and the contact force of the mobile device. The constraint equation of the vehicle system can be expressed as:
\[ C(q,t) = \begin{bmatrix} R_{0,x} + c_1 \\ R_{0,y} + c_2 \\ \theta_0 \\ R_i + A_j \overline{p}_{0,i} - R_i - A_i \overline{p}_{0,i} \\ \vdots \\ R_i + A_i \overline{p}_{n,i} - R_{i+1} - A_{i+1} \overline{p}_{n,i+1} \\ \vdots \\ R_{n-1,i} + A_{n-1,i} \overline{p}_{n-i,n} - R_n - A_n \overline{p}_{n-i,n} \end{bmatrix} = 0 \]

And the system of the external force vector is obtained through the calculation of the generalized force in multi-body system. In the tracked vehicle system, contact collision model include: track - road wheel, track - induced wheel, track - driving wheel and track – ground, et.al.

In rigid body system dynamics, the calculation of contact force can be expressed as:

\[ F_{ij} = k \delta_{ij}^n + c \dot{\delta}_{ij} \]

The k and c are the stiffness and damping coefficient; \( \delta_{ij} \) is defined as the penetration degree, and \( \delta_{ij} = R_{y,i} - R_{y,j} - r \)

The virtual work equation of contact force is:

\[ \delta W = F_{ij} \begin{bmatrix} \partial r_{pi} \\ \partial q_i \\ \partial q_j \end{bmatrix} \begin{bmatrix} \delta q_i \\ \delta q_j \end{bmatrix} = Q_i^T \delta q_i + Q_j^T \delta q_j \]

\[ Q_i = \begin{bmatrix} Q_{R,i} \\ Q_{\theta,i} \end{bmatrix} = F_{ij} \begin{bmatrix} 1 \\ \overline{p}_{i} A_{i,j}^T \end{bmatrix} r_{p,i} \]

\[ Q_j = \begin{bmatrix} Q_{R,j} \\ Q_{\theta,j} \end{bmatrix} = F_{ij} \begin{bmatrix} 1 \\ \overline{p}_{j} A_{j,i}^T \end{bmatrix} r_{p,j} \]

The displacement in the generalized coordinate system is defined as

\[ r_{pi} = r_{pj} - r_{pj} = R_i + A_i \overline{p}_i - R_j - A_j \overline{p}_j \]

**The Virtual Prototype Model of Tracked Vehicle**

In the process of modeling of tracked vehicle, the body is the basic entities, all wheels are connected with the body. The track system is consist of wheel and track. The impact parameter of vehicle and the ground is defined in crawler system. There are many crawler systems in the tracked vehicle, each crawler system have its own parameters of road and pavement. Driving wheel is linked to the body through a rotational vice, the rotation or torque to the relative body can be defined to make the vehicle move.

Return roller is connected to the body through a spin vice. Road wheel supported by the suspension is connected to the body. Track tension device in inducing wheel is connected to the body to keep the appropriate tension degree of the track.

Suspension system is simulated by rotary spring and mobile damping, the stiffness coefficient of the tension device and damping coefficient is set, the tensioning force is decided by the length of the
tension device. The reference position and direction of body is defined in the generalized coordinate system. The position and direction of the crawler system is defined in the body coordinate system to define, the position and direction of crawler system entity is defined in the crawler system coordinate.

Some type of high speed tracked vehicle with presented in Fig. 1.1. Gross vehicle weight is 28 t, there are five road wheels, 1 return roller and 73 pieces of crawler plate for each side track system, the length of track pitch is 0.15 m, the width is 0.44 m, the landing length of crawler is 2.92 m, the length of gauge of crawler vehicle is 2.54 m, the total degrees of freedom is 908. The global coordinate system of the vehicle model is defined in the body.

![Figure 1. Virtual prototype model of tracked vehicle.](image)

The angular velocity of the driving wheel is set to ensure that the initial time of angular velocity match the vehicle speed at the beginning. If do not match, a great force and torque will appear between the driving wheel and the track, leads to the wrong simulation results. The shape of tooth of driving wheel has an important role in simulation.

Torsion spring and translational dynamic damper cantilever are adopted in suspension system. Another important part in crawler vehicle mobile device is crawler tension device, which can not only adjust the tension force timely in the process of vehicle, but also guarantee the stability of the track link, prevent the track from taking off the wheel, thus ensure the durability of the tracked driving device.

### Simulation of the Tracked Vehicle Climbing Over Vertical Wall

The height of the vertical standing obstacle, is defined as the ability to climb over. The ability to climb over vertical wall is the important index to ensure mobility of high off-road vehicle. The maximum value is depended upon the position of vehicle's gravity and mobile device, et.al..

The process of tracked armoured vehicle climbing overcome vertical wall can also be divided into three stages: the first stage, the front wheel (induced wheel or driving wheel) climb on the wall edge, as shown in Fig. 2; the second phase, as shown in Fig. 3, the centre of gravity of the tanks moves forward and coincide with the perpendicular of the vertical wall; the third stage, the bottom of the tank contact with the top plane of the vertical wall gently, as shown in Fig. 4.

![Figure 2. The first stage of climbing over vertical wall.](image)

![Figure 3. The second stage.](image)

![Figure 4. The third stage.](image)
Figure 5. The compared response curve of angular acceleration of the driving wheel.

Figure 6. The compared response curve of angular velocity of the driving wheel.

Figure 7. The compared response curve of displacement of the body in the longitudinal direction.

Figure 8. The compared response curve of displacement of the body in the vertical direction.

Figure 9. The compared response curve of velocity of the body in the longitudinal direction.
The compared responses curve of the driving wheel, body, track section in running state, between the 0.8 meter-high vertical wall and the 0.7 meter-high vertical wall are presented from Fig. 5 to Fig. 10. When the height of the vertical wall is more than 0.9 meters, the tracked vehicle can't climb the wall edge in the first stage.

Conclusions
A great deal of simulation work is done to the ability of obstacle-navigation of tracked vehicle, especially the ability to climb over the trench. The simulation process proposed in the paper can reflect the actual running state of the tracked vehicle more truly compared with the traditional static analysis.

For the real vehicle test of climbing trench and climbing over vertical wall, there is the problems of falling or upsetting, thus the passengers and drivers will encounter the risk of security. The times for test can be reduced through the simulation, the test security can be improved, and the corresponding analysis can provide the theory reference to real vehicle control.

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Reference