

# Analysis on Three Kinds of Framework for Sojourner's Six-wheeled Rocker Suspension

MA Jin-sheng<sup>1</sup>, CHENG Jiu-ru<sup>2</sup>, ZHUANG Da-min, GONG Hao-qin  
BEIHANG University, 37# Xueyuan Road, Haidian District, BeiJing, 100191 China  
<sup>1</sup>mjs99@126.com  
<sup>2</sup>machera19850215@126.com

**Abstract**—The climbing vertical obstacle capability is one of the important assessment indicator for the planet exploration vehicle. The Sojourner planet rover represents the leading level of a hot research area - the wheel style. The analysis of Sojourner's over-obstacle principle and its process were introduced, and it was expressed by 7 parameters. The selection of the driven moment for the machine and the mathematic model were also discussed. According to the actual movement, the rolling friction was drawn into the model and an instance was given. Finally, the capability of triangle, rectangle, arc framework was analysed and researched based on the mechanics model of Sojourner's six-wheeled rocker suspension, their mathematic models were established using the same method as the second part of the paper, and sketches of the obstacle crossing capability were drawn using Matlab, then the triangle framework was proved to have the best capability.

**Keywords**—rocker suspension; obstacle crossing; triangle framework; rectangle framework; arc framework

## I. INTRODUCTION

One important step of exploring the unknown universe is the moon exploration. Despite there are a variety of ways to complete the detection of the moon, the most direct means is delivering the planet exploration vehicle to the planet, one of the key factors determining the success. Currently, space exploration robot can be divided into wheel style, leg style, pedrail style and complex style. The last three styles can fit even terrain very well, but have complicated structure. Moreover, the technology for the leg style has not yet refined; the pedrial style has large energy consumption and low efficiency; the behavior programming for the complex style is complicated. On the other side, the wheel style

has poor adapting terrain ability, but it possess abundant merits, such as high speed and efficiency, simple framework, as a result, the wheel style is the research hotspot, for example, Sojourner planet rover developed by Jet Propulsion Laboratory[1] representing the leading level of the wheel style.

Roaming on the surface of the planet, various obstacles will be encountered by the rover, especially one of the important assessment indicator for the rover is the climbing vertical obstacle capability. In order to enhance the climbing obstacle capability and the institution efficiency, different kinds of Sojourner's six-wheeled rocker suspension have been analysed, and the driving moment and rolling friction were draw into the model.

## II. THE PRINCIPLE ANALYSIS OF SOJOURNER'S SIX-WHEELED ROCKER SUSPENSION

The six-wheeled rocker suspension was adopted by Sojourner planet rover, making the rover can fit the terrain well. The schematic diagram of the suspension was shown in Fig1.

The principle analysis[2]:travelling on the flat ground, the whole machine move steadily, the A and B hinges don't operate, the main and assistant rocker don't change, the mechanism of the moment is similar to the familiar four-wheeled machine; coming into contact with the obstacle, with the driven force, the assistant rocker

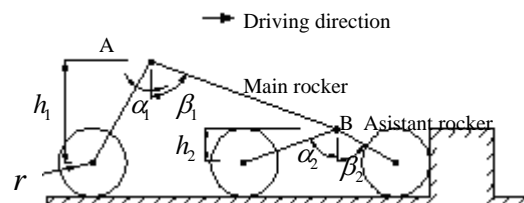


Fig1. the schematic diagram of the six-wheeled rocker suspension

revolves around the B hinge, and the main rocker revolves around the A hinge, then the forward wheels climb up the obstacle, afterwards the remaining wheels can over the obstacle easily. Due to the selfadaptive suspension, the climbing obstacle capability is greatly improved.

Known from the Fig1, the suspension can be reduced to seven parameters:

$h_1$  --the height between the A hinge and the center of the driven wheel;

$\alpha_1$  --the angle between the rear wheel's connecting rod of the main rocker and the vertical line;

$\beta_1$  --the angle between the vertical line and the connecting rod of the main rocker and the assistant rocker;

$h_2$  --the height between the hinge point of the main rocker and the assistant rocker and the center of the driven wheel;

$\alpha_2$  -- the angle between the middle wheel's connecting rod of the assistant rocker and the vertical line;

$\beta_2$  --the angle between the vertical line and the forward wheel's connecting rod of the assistant rocker;

$r$  --the radius of the driven wheel.

### III. THE SELECTION OF THE DRIVEN MOMENT

When the forward wheel is departing from the ground climbing along the barrier, the force analysis of the rocker suspension is shownd in Fig2. where G represents the force effecting on one side of rocker suspension by the gravity of the main body;  $G_Z(G_F)$  represents the gravity of the main(assistant) rocker;  $G_L$  represents the gravity of the wheel;  $N_Q(N_Z, N_H)$  represents the supporting force of the forward(middle, rear) wheel effecting by the ground;  $f_Q(f_Z, f_H)$  represents the friction between the forward(middle, rear) wheel and the ground;  $M_Q(M_H)$  represents the driven moment of the forward(rear) wheel;  $M_{fQ}(M_{fZ}, M_{fH})$  represents the couple of rolling resistance between the forward(middle,

rear) wheel and the ground. According to the prototype, the amount of  $G(G_Z, G_F, G_L)$  is 250(15, 10, 40) N.

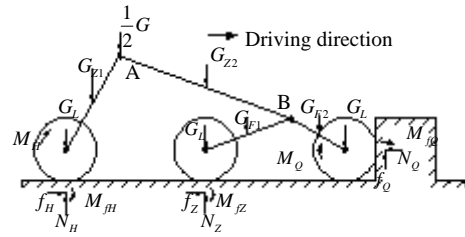


Fig2 the force analysis of the rocker suspension

Now the equation of force and moment equilibrium can be educed from the whole organization:

$$N_Q = -f_Z + f_H \quad (1)$$

$$f_Q + N_Z + N_H = 0.5G + G_{Z1} + G_{Z2} + G_{F1}$$

$$+G_{F2} + 3G_L = 0.5G + G_Z + G_F + 3G_L \quad (2)$$

$$G_{Z1} \cdot 0.5h_1 \tan \alpha_1 - G_{Z2} \cdot 0.5(h_1 - h_2) \tan \beta_1$$

$$-G_{F1} \cdot [0.5(h_1 - h_2) \tan \beta_1 - 0.5h_2 \tan \alpha_2]$$

$$-G_{F2} \cdot [0.5(h_1 - h_2) \tan \beta_1 \cdot [0.5(h_1 - h_2) \tan \beta_1$$

$$+0.5h_2 \tan \beta_2] + G_L \cdot h_1 \tan \alpha_1 - G_L \cdot [0.5(h_1$$

$$-h_2) \cdot \tan \beta_1 - 0.5h_2 \tan \alpha_2] - N_Q \cdot h_1$$

$$+ N_Z \cdot [0.5(h_1 - h_2) \tan \beta_1 - 0.5h_2 \cdot \tan \alpha_2]$$

$$- N_H \cdot h_1 \tan \alpha_1 + f_Q \cdot [0.5(h_1 - h_2) \tan \beta_1$$

$$+0.5h_2 \tan \beta_2 + r] - f_Z \cdot [h_1 + r] + f_H \cdot [h_1 + r]$$

$$-M_{fQ} + M_{fZ} - M_{fH} - M_Q - M_H = 0 \quad (3)$$

The equation of moment equilibrium can be educed from the assistant rocker and the middle, forward wheels:

$$G_{F1} \cdot 0.5h_2 \tan \alpha_2 - G_{F2} \cdot 0.5h_2 \tan \beta_2 + G_L \cdot h_2 C$$

$$-G_L \cdot h_2 \tan \beta_2 - N_Q \cdot h_2 - N_Z \cdot h_2 \tan \alpha_2$$

$$+ f_Q \cdot [h_2 \tan \beta_2 + r] - f_Z \cdot [h_2 + r] - M_{fQ} + M_{fZ}$$

$$-M_Q = 0 \quad (4)$$

Equations of moment equilibrium can be educed from the forward, middle, rear wheels:

$$M_{fQ} + M_Q = f_Q \cdot r \quad (5)$$

$$M_{fZ} = f_Z \cdot r \quad (6)$$

$$M_{fH} + M_H = f_H \cdot r \quad (7)$$

And equations can be educed from the rolling friction:

$$M_{fQ} = N_Q \cdot \delta' \quad (8)$$

$$M_{fZ} = N_Z \cdot \delta \quad (9)$$

$$M_{fH} = N_H \cdot \delta \quad (10)$$

In order to simplify the model, suppose  $M_Q = M_H$ . According to the above equations, the following condition should be necessary by the driven moment when this machine is able to over the barrier, whose height is higher than the radius of the wheel:

$$M_Q \geq \frac{AG + BG_Z + CG_F + DG_L}{E}$$

For example:

$$A = \frac{1}{8} [h_1 (\tan \beta_1 - 2 \tan \alpha_1) - h_2 (\tan \beta_1 - 2 \frac{\delta}{r})] + \frac{1}{8} \{h_1 \cdot (\frac{\delta'}{r} - \frac{r}{\delta}) \cdot (2 \tan \alpha_1 + \tan \beta_1) + h_2 \cdot [(-\frac{\delta'}{r} + \frac{r}{\delta}) \tan \beta_1 - 2(\frac{\delta \delta'}{r^2} - 1)]\}$$

When  $h_1 = 300mm$  ,  $h_2 = 100mm$  ,  $\alpha_1 = 30^\circ$  ,

$\alpha_2 = 70^\circ$  ,  $\beta_1 = 70^\circ$  ,  $\beta_2 = 60^\circ$  ,  $r = 100mm$  , we can get

$$M_Q \geq 20.92N \cdot m$$

It means that the driven moment should be more than or equal  $20.92N \cdot m$  when this machine is able to over the barrier, whose height is higher than the radius of the wheel.

### III. ANALYSIS OF THE CLIMBING OBSTACLE CAPABILITY OF DIFFERENT FRAMEWORK

The diagram of the triangle (rectangle, arc) framework of the Sojourner planet rover is shown in Fig3-a (Fig3-b,

Fig3-c).

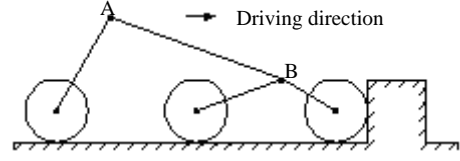


Fig3-a The diagram of the triangle framework

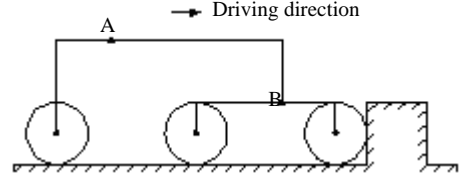


Fig3-b The diagram of the rectangle framework

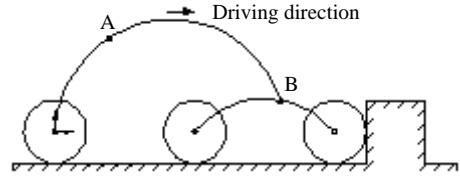


Fig3-c The diagram of the arc framework

According to the analysis method in the part 2, the climbing obstacle capability can be calculated, the driving moment being drawn into the model, afterwards the results were analysed using Matlab software. The turning over step-obstacle capability of the triangle (rectangle, arc) framework is shown in Fig4-a (4-b, 4-c); the spanning salience-obstacle capability of the three kinds of framework is shown in Fig5-a, 5-b, 5-c.

It can be known from Fig4 that the rectangle and arc framework have huge advantage turning over step-obstacle, from Fig5 that the rectangle framework has huge advantage spanning salience-obstacle, moreover the rectangle framework can reach the limit of

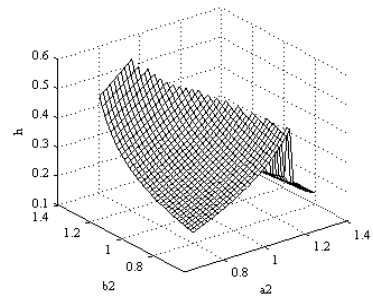


Fig4-a The figure of the turning over step-obstacle capability of the triangle framework

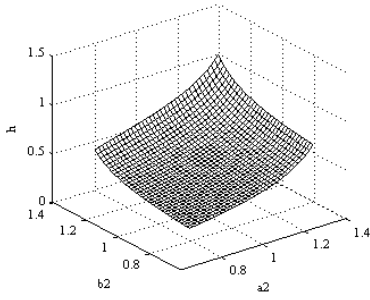


Fig4-b The figure of the turning over step-obstacle capability of the rectangle framework

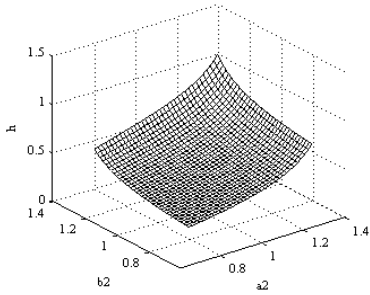


Fig4-c The figure of the turning over step-obstacle capability of the arc framework

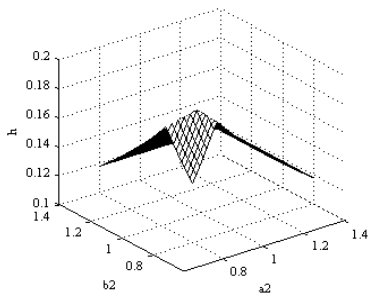


Fig5-a The figure of the spanning salience-obstacle capability of the triangle framework

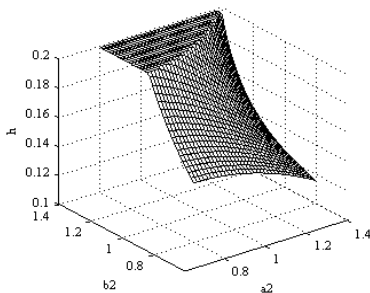


Fig5-b The figure of the spanning salience-obstacle capability of the rectangle framework

the the turning over step-obstacle and the spanning salience-obstacle with the same structure parameters. Therefore, the advantage of the rectangle framework is rather clear.

For example, when  $h_1 = 300mm$ ,  $h_2 = 100mm$ ,

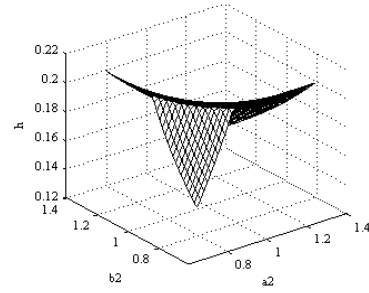


Fig5.-c The figure of the spanning salience-obstacle capability of the arc framework

$\alpha_1 = 30^\circ$ ,  $\alpha_2 = 70^\circ$ ,  $\beta_1 = 70^\circ$ ,  $\beta_2 = 60^\circ$ ,  
 $r = 100mm$ , the rectangle framework can cross 0.42m high step-obstacle and span 0.20m salience-obstacle, the ratio of the obstacle to the radius of the wheel is 4.2 and 2.

#### IV. CONCLUSIONS

- (1) The rolling friction was drawn into the model, which is more according with the real situation.
- (2) The planet exploration vehicle is mainly used when the height of the obstacle is higher than the radius of the wheel, therefore, the driven moment was analysed in advance.
- (3) The planet exploration vehicle is driven by the moment when overing the obstacle, therefore, the driven moment was drawn into the model.
- (4) The climbing obstacle capability of three different framework was researched, and the rectangle framework has much more advantage.

#### REFERENCES

- [1] M. Tarokh, G.. McDermott, S. Hayati. etc. "Kinematic modelling of a high mobility mars rover," *Proceeding of the 1999 IEEE, International Conference on Robotics & Automation Detroit, Michigan*, pp. 992~998, May 1999.
- [2] 侯绪研, 高海波, 胡明, 邓宗全, 基于越障性能的六轮摇臂式月球探测车悬架尺寸优化设计. *宇航学报*. 2008.3 第 29 卷第 2 期: 420~425.
- [3] 胡明, 邓宗全, 高海波, 王少纯, 摇臂-转向架式月球探测车越障通过性分析. *上海交通大学学报*. 2005.6 第 39 卷第 6 期: 928~932.