Design of Retracting Wheel Mechanism for Amphibious Vehicle and Motion Analysis

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Abstract- This paper mainly addresses design of retracting mechanism based on amphibious vehicle's low speed and strong resistance in water. Through analyzing problems faced in the design of amphibious vehicle, one kind of retracting mechanism based on double-wishbone independent suspension is proposed. The equations of key-points at suspension guiding mechanism are obtained, and the relationship between the length of hydraulic stick retracted and the height of wheel lifted are also calculated. Finally, a specific 3D model is built, and wheel alignment is determined, therefore a real mechanism is assembled to illustrate the retracting mechanism.

Introduction

In recent years, flood disasters happened frequently because global climate is changing. The amphibious vehicle gets more attentions. It can play a unique performance in junction of land and water. Amphibious vehicle plays important roles in rescuing in flood disaster, and has also became essential weapons especially coast defense. The UK and Switzerland that developed the high-speed amphibious vehicle named Aquada and Splash have the leading position around the world [1]. But many key technological problems have to be solved in order to suffice the function of the amphibious vehicle, and the retracting wheel mechanism is one of the key technological problems in water. According to a study in U.S, the resistance of wheel in water accounts for 25% of vehicle resistance [2], so retracting wheels into the wheel housing can prevent them from dragging through the water and enable the amphibious vehicle to plane faster and maneuver better. For the purpose of high speed cruising, the guiding mechanism of suspension is needed to redesign [3, 4].

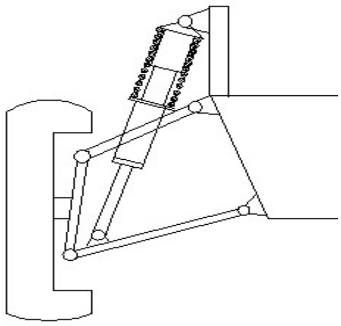

Fig.1 Direct-retracting (on land)

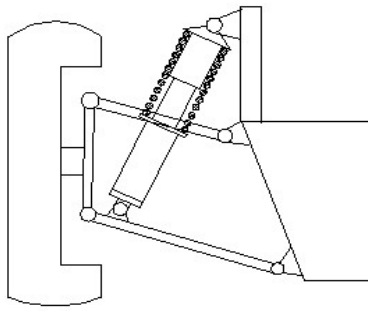

Fig.2 Direct-retracting (in water)

Through analyzing above, the mechanism named direct-retracting is proposed in Fig.1 and Fig.2, the main function of this mechanism provides conventional standards of ride and handing when it is on land, and retracts wheels out of water to reduce hull drag. It is based on double-wishbone independent suspension. The amphibian senses when it is in water, and so will not allow retracting its wheels when on land. Hydraulic pressure is applies to the hydraulic strut, which lifts the wheel to its retracted position [5]. The hydraulic system and shock absorber are combined by line, and the hydraulic system is mounted under shock absorber. The strut hydraulic that needs to provide normal suspension and retract the wheels is the important part of this mechanism.

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Model

Before designing this mechanism, there is a principle needed to notice that the Shock Absorber axis should be vertical with the vehicle longitudinal axis. The purpose is that the interference is avoided between shock absorber and lower control arm when lifting wheel (as shown in Fig.3.).

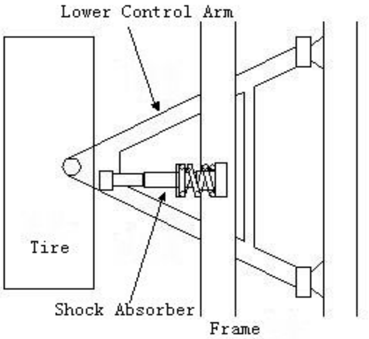

Fig.3 Diagram of Shock Absorber mounted

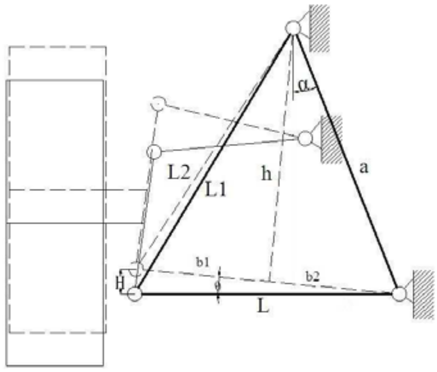

Fig.4 Diagram of lifting mechanism

The Relationship of Direct-retracting Motion. As shown in Fig.4, the process of movement of direct-retracting is described by the diagram. The situation that amphibian is on land is shown by solid line and in water by dotted line. So some equations are obtained through geometric relationships.

$$\left.\begin{aligned} &\sin(\alpha+\theta)=\frac{b2}{a} \\ &h=a\cos(\alpha+\theta) \\ &\frac{H}{L}=\frac{\pi}{180}\theta \\ &L=b1+b2 \end{aligned}\right\} \text{ Release to } \begin{cases} \theta=\dfrac{180}{\pi L}H \\ b1=L-a\sin(\alpha+\theta) \end{cases} \tag{1}$$

Where L is the length of lower control arm, L1 is the length of hydraulic system (normal), L2 is the length of hydraulic system (retracting), *a* is distance from the upper point of hydraulic system to axis of lower control arm, α is the angle between *a* and vertical direction, H is the height of wheel lifted in the case <300mm which the height of lower ball joint lifted is considered as the height of wheel lifted. They are known as the parameters of vehicle except L2 and H. It is easy to show that the relationship from above diagram:

$$\left.\begin{aligned} &L2^2=b1^2+h^2 \\ &\Delta=L1-L2 \end{aligned}\right\} \tag{2}$$

Where Δ which is retractable length of hydraulic system is given by equation only expressed as H:

$$\begin{aligned} \Delta &= L1-L2 \\ &= L1-\sqrt{\left[L-a\sin(\alpha+\frac{180}{\pi L}H)\right]^2+\left[a\cos(\alpha+\frac{180}{\pi L}H)\right]^2} \end{aligned} \tag{3}$$

Equation (3) is only applied to the mechanism based on double-wishbone independent suspension.

Motion Analysis of Independent Suspension Guiding Mechanism. When the guiding mechanism of front wheel suspension is designed, two points are noticed: 1) when the vehicle is driving, tread should be on certain range; 2) when front wheel is jump up and down, wheel alignment has reasonable change [6, 7].

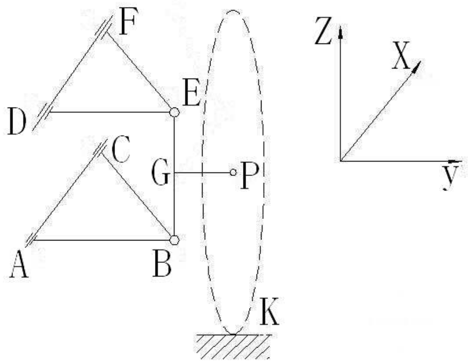

Fig.5 Diagram of independent suspension

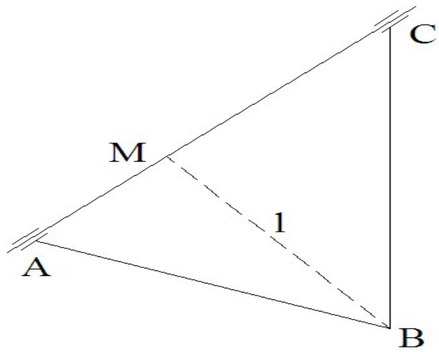

Fig.6 Diagram of lower control arm

As shown in Fig.5, AC is lower control arm bushing, B is lower ball joint, GP is the shaft, and K is point of wheel on ground. A and C are shown by coordinate $A(X_A, Y_A, Z_A), C(X_A, Y_A, Z_A)$, so the direction of vector AC is shown

$$n = \{X_C - X_A, Y_C - Y_A, Z_C - Z_A\} = \{1, A1, B1\}$$

Where: $A1 = (Y_C - Y_A)/(X_C - X_A)$; $B1 = (Z_C - Z_A)/(X_C - X_A)$

Line AC is described by equation (4):

$$\frac{X - X_A}{X_C - X_A} = \frac{Y - Y_A}{Y_C - Y_A} = \frac{Z - Z_A}{Z_C - Z_A} = t \tag{4}$$

The plane which is vertical with AC and passes B is described by equation:

$$X - X_B + A1(Y - Y_B) + B1(Z - Z_B) = 0 \tag{5}$$

M coordinate is obtained by equation (4) and equation (5):

$$X_M = t + X_A$$
$$Y_M = A1t + Y_A$$
$$Z_M = B1t + Z_A$$

Where: $t = [X_B - X_A + A1(Y_B - Y_A) + B1(Z_B - Z_A)]/(1 + A1^2 + B1^2)$

The length of BM is described by equation (6):

$$l = \sqrt{(X_B - X_M)^2 + (Y_B - Y_M)^2 + (Z_B - Z_M)^2} \tag{6}$$

The equation of track B, which is a sphere that uses M to the center of sphere, is expressed as

$$(X - X_M)^2 + (Y - Y_M)^2 + (Z - Z_M)^2 = l^2 \tag{7}$$

When wheels jump up and down, the final equation of B is obtained by equations (5) and (7).

$$\begin{cases} X - X_B + A1(Y - Y_B) + B1(Z - Z_B) = 0 \\ (X - X_M)^2 + (Y - Y_M)^2 + (Z - Z_M)^2 = l^2 \end{cases} \tag{8}$$

Through analysis above, similarly, the equation of E can be formulated.

$$\begin{cases} X - X_F + A2(Y - Y_F) + B2(Z - Z_F) = 0 \\ (X - X_N)^2 + (Y - Y_N)^2 + (Z - Z_N)^2 = q^2 \end{cases} \tag{9}$$

Where

$$A2=(Y_F-Y_D)/(X_F-X_D), B2=(Z_F-Z_D)/(X_F-X_D)$$
$$q=\sqrt{(X_F-X_N)^2+(Y_F-Y_N)^2+(Z_F-Z_N)^2}$$
$$X_N=p+X_D, Y_N=A2p+Y_D, Z_N=B2p+Z_D$$
$$p=[X_E-X_D+A2(Y_E-Y_D)+B2(Z_E-Z_D)]/(1+A2^2+B2^2)$$

Wheel alignment. Wheel alignment is the process of measuring and correcting the various angles formed by the front wheels, spindles, and steering arm. According to Fig.5, alignment can be given.

Caster: $\alpha=\arctan(\frac{X_B-X_E}{Z_B-Z_E})$ Steering axis inclination: $\beta=\arctan(\frac{Y_B-Y_E}{Z_B-Z_E})$

Camber: $\gamma=\arctan(\frac{Z_G-Z_H}{Y_G-Y_H})$ Toe angle: $\delta=\arctan(\frac{X_G-X_H}{Y_G-Y_H})$

Application

Through analysis above, one real prototype is assembled to realize the retracting movement. Based on the prototype chassis, the retracting mechanism model is built and simulated through UG package (as shown in Fig.7 and 8):

Fig.7 The entity of retracting mechanism

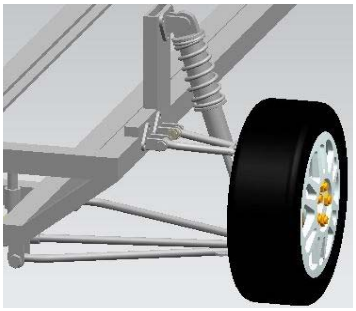

Fig.8 The 3D-model of retracting mechanism

The coordinate of points in Fig.5 is extracted from UG package and shown in Table 1. For this, the wheel alignment is obtained.

$\alpha=0.36^\circ, \beta=5.9^\circ, \gamma=1.14^\circ, \delta=1.72^\circ$

If wheels jump in the range from -40mm to 40mm that reflect the deflection caused by road roughness when vehicle is driven on land, the range of wheel alignment is shown as

Caster: 0.35°～0.37°; Steering axis inclination: 5.5°～9.3°;

Camber: 1.03°～2.5°; Toe angle: 1.3°～2°;

Table 1 the coordinate of points

point \ coordinate	X	Y	Z
A	233	-540	-117
B	1.5	***-5***	***-120***
C	-232	-540	-117
D	-15	-376	156
E	0	***-30***	***121.6***
F	171	-352	169
G	0	0	0
P	1.5	50	-1
K	2.65	48.5	-251

Through analyzing above data, wheel alignment is reasonable except that steering axis inclination has large changes due to the position of Kingpin (described by BE coordinate in Table 1), but the function of suspension is barely influenced, therefore the design of suspension for retracting mechanism is feasible.

Conclusions

In order to solve the problem that amphibious vehicle has low-speed in water, the direct-retracting mechanism is designed. Through kinematic analysis for the mechanism, the equations that describe track of points of suspension are driven, and the relationship between the length of hydraulic stick retracted and the height of wheel lifted is obtained. The results of wheel alignment show that the direct-retracting mechanism based on double-wishbone independent suspension can be used in amphibious vehicle to improve its driving performance. It is expected that the results shown in this paper could be applied to the design of new amphibious vehicle.

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