Modeling and Simulation of Modular Independent Oil and Gas Suspension Mechanics

Yijie Chen, Yafeng Zhang, Mengyan Xu, Le Wang and Xiaoling Han
China North Vehicle Research Institute, Beijing
chenyijie1206@163.com

Abstract. The modular independent oil and gas suspension had become the key to achieving high maneuvering off-road capability for a new generation of military special vehicles, aiming at this situation, the modeling of characteristics of modular independent suspension and oil gas spring were researched. It was proposed to use the actual gas state equation to derive the nonlinear elastic properties, and took the double wishbone independent suspension as the main research object to complete the analytical calculation of the kinematics and dynamics of the guiding mechanism, after that the force state of each hard point coordinate was clarified. The simulation analysis of the suspension characteristics and key parameters with displacement was carried out by programming, and the mechanical influence law of the independent oil and gas suspension system was revealed, which laid a foundation for engineering design.

1. Introduction
Double wishbone independent suspension was one of the most commonly used suspension types. At the yield of automobile, it had an extensive application, request to have dependable dynamics function of stability. The prominent advantages of the system is design flexibility, it can get suitable motions through change the length of the control arm and the position of guiding rod. The performance of suspension is related to many factors, so it is researched by establishing double wishbone independent suspension model in this article.

2. Double Wishbone Independent Suspension Physical Model
As shown in Figure 1, it is the double wishbone independent suspension which contains the upper and down wishbones, and the oil gas spring is installed on it. The oil gas spring has nonlinear elastic performance, which can improve the vehicle cross-country mobility obviously.
3. The Mathematical Model of Independent Suspension

3.1. Elastic Performance of Oil Gas Spring
The initial height of the piston rod chamber is:

$$L_{q0} = L_g - L_f$$ (1)

In which, $L_{q0}$ is the initial height of gas chamber, $L_g$ is the length of piston rod, and $L_f$ is the equivalent thickness of floating piston.

The inner cross-sectional area of piston rod is:

$$A_x = \frac{\pi D_x^2}{4}$$ (2)

The initial volume of gas chamber of Oil gas spring:

$$V_{q0} = A_x L_{q0}$$ (3)

The outer cross-sectional area of piston rod is:

$$A_s = \frac{\pi D_s^2}{4}$$ (4)

According to the working principle of oil gas spring:

$$A_x S_f = A_s S$$

$$S_f = A_s A_x^{-1}$$ (5)

In which, $S_f$ is the float piston displacement, and $s$ is the displacement of oil gas spring.

And the chamber length of static balance is:

$$L_j = L_{q0} - A_x S_f A_x^{-1}$$ (6)

In which, $S_j$ is the static balance of oil gas spring.

The arbitrary position of the chamber volume is:

$$V_q = A_x L_j - A_s S$$ (7)

The static positon gas pressure of oil gas spring is[1]:

---

Figure 1. Double wishbone independent suspension
\[ p_j = 4mg \left( \pi D_j^2 \right)^{-1} \] (8)

\[ p = RgT \left( \nu - b \right)^{-1} - a\nu^2 \] (9)

In which, \( p \) is gas pressure, \( T \) is thermodynamic temperature, \( \nu \) is the gas specific volume, \( Rg \) is the gas constant, \( a, b \) is van Derwal constant, and they only relate with the type of gas.

And there is[2]:

\[ p = RgT_{m_q} \left( V - m_q b \right)^{-1} - a m_q^2 V^{-2} \] (10)

In which \( m_q \) is the gas quality.

The gas quality is:

\[ m_q = V_{q_l} \left[ 0.17 D \left( ab \right)^{-1} - 0.67 \left( 3b \cdot Rg \cdot T_0 + 3p_j b^2 - a \right) b^{-1} D^{-1} + 0.33b^{-1} \right] \] (11)

In which

\[ V_{q_l} = A_x L_{q_0} - A_x S_j \]

\[ M = Rg^2 \cdot T_0^2 \left( 4b \cdot Rg \cdot T_0 + 12p_j b^2 - a \right) \]

\[ N = 4p_j \left( 3p_j b^3 \cdot Rg \cdot T_0 - 5abRg \cdot T_0 + b^4 p_j^2 + 2ab^2 p_j + a^2 \right) \]

\[ C = -36b \cdot Rg \cdot T_0 + 72p_j b^2 + 8a \]

\[ D = \left( C + 20.78 \left( \left( M + N \right) / a \right)^{0.5} b \right) a^2 \]

(12)

Through the formula (10), it can solve the gas pressure of arbitrary temperature and volume.

3.2. Performance of Double Wishbone Independent Suspension

As shown in Figure 1, the hinges A and E are connected, and the distance between the two points is:

\[ |AE| = \sqrt{\left( x_e - x_s \right)^2 + \left( y_e - y_s \right)^2} \] (13)

And the angle between the two points connection line with the horizontal line can be obtained:

\[ \theta = \arctan \left( \frac{y_e - y_s}{x_e - x_s} \right) \] (14)

\( \delta \) is the angle between the line AF with upper wishbone AB of suspension. In the \( \Delta AEF \), the line EF is the length of oil gas spring:

\[ L = \sqrt{|AE|^2 + |AF|^2 - 2|AE||AF| \cos(\alpha + \theta - \delta)} \]

\[ \angle AEF = \arcsin \left[ \frac{|AF|}{|EF|} \sin(\alpha + \theta - \delta) \right] \] (15)
\[ \varphi = \frac{\pi}{2} - \theta - \angle AEF \]

In which \( \varphi \) is the angle between oil gas spring axis with vertical line.

Wheel travel \( y \) by the following formula [3-4]:

\[ y = |J_0K_0| - |JK| \]

\[ |J_0K_0| = |AB| \sin \alpha_0 + |G_0B_0| \cos(\lambda + \gamma_0) \]

\[ |JK| = |AB| \sin \alpha + |GB| \cos(\lambda + \gamma) \]

So the wheel travel \( y \) is:

\[ y = |AB|(\sin \alpha_0 - \sin \alpha) + |GB|(\cos(\lambda + \gamma_0) - \cos(\lambda + \gamma)) \]  \hspace{1cm} (16)

The kingpin inclination angle \( \gamma \) in the formula can be obtained from the relationship between the corners of the four-bar linkage mechanism composed of the suspension structure.

Connect the two hinges A and C, and set their angle to the horizontal line is \( \theta_0 \):

\[ \theta_0 = \arctg \frac{Y_a - Y_d}{X_a - X_d} \]  \hspace{1cm} (17)

From the analysis of the four-bar linkage mechanism in the mechanical principle:

\[ \gamma = \arctg \frac{|CD| \cos \beta - |AB| \cos \alpha - (x_a - x_d)}{y_a - y_d - |AB| \sin \alpha + |CD| \sin \beta} \]  \hspace{1cm} (18)

In which:

\[ \beta = 2\arctg \frac{a - \sqrt{a^2 + b^2 - c^2}}{b - c} - \theta_0 \]

\[ a = - \sin(\alpha + \theta_0) \]

\[ b = - \frac{|AD|}{|AB|} \cos(\alpha + \theta_0) \]

\[ c = \frac{|AD|^2 + |CD|^2 + |AB|^2 - |BC|^2}{2|AB||CD|} + \frac{|AD|}{|CD|} \cos(\alpha + \theta_0) \]

And

\[ |AB| = \sqrt{(x_a - x_d)^2 + (y_a - y_d)^2} \]

From the above derivation, we can obtain the maximum and minimum length of the oil and gas spring work according to the suspension stroke. The structural design of the oil and gas spring can then be carried out according to the lateral space of the installation. It must be noted that in the specific design, factors such as installation accuracy should be considered, and a certain margin must be left, that is, the maximum length of the design should be greater than the calculated maximum
length, and the minimum length of the design should be less than the calculated minimum length. The
design stroke of the oil and gas spring is made larger than the calculated stroke to ensure the normal
and safe operation of the oil and gas spring during the full stroke of the suspension.

4. Performance Calculation of Independent Suspension
The double wishbone points of static position are: A(414, -209.3), B(922.8, -274.8), C(467.9, -579.8),
D(1014.9, -673.8), E(762.9,90.2), F(762.9, -619.8), H(1265.5, -1054). The different parameters of
suspension following the displacement can be solved through the above formulas as follows:

![Figure 2. Leverage ratio follow the wheel travel](image1)

![Figure 3. Spring axis swing angle follow the wheel travel](image2)

![Figure 4. Spring pressure follow the wheel travel](image3)

![Figure 5. Suspension stiffness follow the wheel travel](image4)
As shown in Figure 2-7, the mathematical model of double wishbone independent suspension could be calculated through Matlab, and researchers can analyze the influence of important parameters of suspension on the vehicle ride comfort and handling stability, the conclusion could be used as a reference for design of the device.

5. References

[1] CHEN Yi-Jie. Research on Analytical Computation of Valve Parameters and Design of Hydro-pneumatic Spring. 2008 [J] Beijing: Beijing Institute of Technology.

[2] Gourgoulhon E. An introduction to relativistic hydrodynamics 2006 [J]. Stellar Fluid Dynamics and Numerical Simulations, 54(3): pp43-79.

[3] Chen Yijie, GU Liang, GUAN Ji Fu. Research on the mathematical model and analysis the throttle aperture of hydro-pneumatic spring 2008 [J]. Beijing Institute of Technology, 5: pp388-391 (In Chinese).

[4] Alinger M J, Van Tyne C J. Evolution of die surfaces during repeated stretch-bend sheet steel deformation 2003 [J]. Journal of Materials Processing Technology, v141, 41(3): pp 411-419.