Model and dynamic performance analysis of mountain tractor suspension implements

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Abstract. A tractor three degree of freedom of agricultural implement suspension mechanism is proposed. The position and posture of the agricultural suspension implement frames are controlled by adjusting these three active motion pairs. Since the agricultural suspension implement is fixed on the mountain tractor through three points, the adjustment of the agricultural implement position and posture is obtained. Corresponding dynamic performance analysis of the mountain tractor suspension implements is analyzed. This model can be used for the operation of the tractor and farm implement set with automatic chassis levelling on the slope. The farm implement and the slope terrain can be profiled by adjusting the position and posture of the farm implement, and the lateral uniformity of the cultivation depth can be improved.

1. Introduction

Compared with the higher level of agricultural mechanization in the vast plain areas of China, the level of agricultural mechanization in hilly and mountainous areas is still very low, which has become a bottleneck for China to fully realize agricultural mechanization[1]. The reasons for the lower level of agricultural mechanization in hilly areas include the low level of agricultural machinery operations in hilly areas and the harsh operating conditions. The most important reason is that the existing agricultural machinery lacks adaptability to mountain slope operations[2-3]. Due to lack of the adaptability to slopes, the operation of agricultural machinery shows the difficulty in keeping the vehicle chassis level and easy to tip, which seriously affects the safety of operators[4]. At the same time, the tractor suspension implement is short of terrain profiling, which leads to poor operation quality. Northwest Agricultural University proposed a smart crawler tractor with adjustable flat chassis, and Jiangsu University proposed a wheeled tractor with adjustable flat chassis.

Regarding the chassis of the tractor has the function of slope leveling adjusting, the tractor suspension implement needs to be controlled by the attitude of the farm implement. It has been established that the contouring operation of the rotary tiller implement on the slope can ensure the uniformity of the depth of cultivation. At the same time, this leveling function also avoids the partial traction of the farm implement phenomenon. Thus, to solve this problem, some universities and research institutes have improved on the traditional three-point implement by using a lifting arm and rod to control the position of the corresponding pull-down rod. Therefore, it can achieve the control of the farming tool depth and the tilt angle of the farming tool[5-7].
Due to the traditional three-point suspension rod, the farm implement has one degree of freedom to rotate around the drive axle. The other degree of freedom is the horizontal swing degree of freedom, which rotates around the vertical direction. However, the lifting arm can only control the degree of freedom to rotate around the drive axle. Though this degree of freedom can control the height position of the tractor implement, it cannot limit the freedom of lateral swing of the tractor implement. During the work of the agricultural implement on the slope, the gravity of the agricultural implement will cause the agricultural implement to swing laterally[8]. The existence of this lateral swing or disturbance will then lead to an actual rollover of the tractor. This partial traction phenomenon as the tractor suspension implements cultivate affects the straight working and safety of the tractor suspension implements slope operation.

2. Suspension implement model and mechanical equation

In order to control the suspension implement position posture and adjust the depth of the mountain tractor implement, the three degree of freedom of the mountain tractor suspension implement is presented in this paper. A tractor model with three degree of freedom agricultural implement suspension mechanism is set. The model can be used to achieve the control of the position and posture of the tractor implement, and adjust the tillage depth of the agricultural implement and the contour of the slope[9-10].

2.1. Suspension implement model

The suspension implement model is shown in Fig1. Here the three degree of freedom suspension device is composed of a left telescopic pulling rod, a right telescopic pulling rod, a pull-down rod, and an agricultural implement attachment frame.

![Figure 1. Model for mountain tractor suspension implements](image1)

![Figure 2. Analysis diagram of the left (right) telescopic rod freedom](image2)

It can be seen from the two above figures, the left and right telescopic rods are devices with moving pairs, which can be extended or shortened. One end of the left telescopic rod and the right telescopic rod is hinged with the tractor body through a ball pair, and the other end is hinged with the ball pair to the frame of the tractor implement. Figure 2 shows that one end of the pulling-down rod is connected to the body through the rotating pair, and the other end is connected to the hinged frame through the U-shaped pair. It is clearly seen here the U-shaped pair has two orthogonal rotation degrees of freedom. One rotation direction is parallel to the direction of the rotation pair with the pulling rod on the tractor body, and the other rotation direction is parallel to the plane normal of the farming implement attachment frame. Therefore, the three suspension points are connected with the hanging points of the tractor implements to carry out the three points suspension of the tractor implements.
As shown in Figure 3, one end of the pull-down lever (4) is connected to the tractor body (1) through a rotating pair (11 (R)), and the other end is connected to the frame of the agricultural implement through a U-shaped auxiliary. On the pull-down lever (4), the implement is connected with the frame (5) which has three degrees of freedom relative to the tractor body (1). These three degrees of freedom are respectively a rotation degree of freedom around the tractor body \( n_1 \) (rotation pair (11)), a U-shaped pair (16) hinge point \( n_2 \) and \( n_3 \). The rotation degree of freedom \( n_2 \) (rotation angle \( \beta \)) parallel to the direction, and the rotation degree of freedom \( n_3 \) (rotation angle \( \alpha \)) of a U-shaped pair (16) whose hinge point is perpendicular to the plane of the tractor implement coupling frame 5.

### 2.2. Mechanical equation

The following force ordinary differential equations are obtained:

\[
\dot{X}_D = \dot{R}_E^a \cdot \dot{R}_E^b \cdot \dot{R}_E^c \cdot (X_D^E, Y_D^E, Z_D^E, \dot{I})^T
\]  
\( (1) \)

\[
\dot{X}_F = \dot{R}_E^a \cdot \dot{R}_E^b \cdot \dot{R}_E^c \cdot (X_F^E, Y_F^E, Z_F^E, \dot{I})^T
\]  
\( (2) \)

\[
l_1 = \sqrt{\left(\frac{X_D - X_A}{X_D^E - X_A^E} - \left(\frac{Y_D - Y_A}{Y_D^E - Y_A^E}\right)^2 + \left(\frac{Z_D - Z_A}{Z_D^E - Z_A^E}\right)^2\right)}
\]  
\( (3) \)

\[
l_2 = \sqrt{\left(\frac{X_F - X_C}{X_F^E - X_C^E} - \left(\frac{Y_F - Y_C}{Y_F^E - Y_C^E}\right)^2 + \left(\frac{Z_F - Z_C}{Z_F^E - Z_C^E}\right)^2\right)}
\]  
\( (4) \)

According to equations (1) to (4), the target of the roll angle of the tractor implement is \( \alpha \) and the target of the pitch angle of the tractor implement is \( \beta \), the length of the left telescopic rod (2) and the length of the right telescopic rod (3) can be obtained. Therefore, as long as the length of the left telescopic rod (2) and the length of the right telescopic rod (3) are adjusted, the roll angle target \( \alpha \) and the pitch angle target \( \beta \) of the tractor implement attachment frame (5), that is, the roll angle \( \alpha \) and pitch \( \beta \) of the tractor implement is adjustable.

### 3. Results and Analysis

An example of a system simulation of a mountain tractor implement is given by the software AME.
Figure 5. Simulation diagram of the mountain tractor suspension implements

Figure 5 shows the adjusting process of the mountain tractor suspension implements on the slope. As the mountain tractor is connected to the rotary suspension implement to perform rotary tillage on the slope, the left telescopic rod can be adjusted by the manual directional valve length. Then the length of the right telescopic rod through the manual reversing valve can be adjusted. It is assumed here that the tilt angle is 15°, the roll angle of the tractor suspension implement attachment frame is 15°, that is, the rotary tiller is also in a roll posture of 15°, satisfying the contouring operation on the slope field.

Figure 6. Simulation analysis of tractor suspension system

Fig. 6 shows the relationship graph between the suspension implement time and the leveling cylinder. The displacement in the vertical direction has a slight upward trend with time. It is learned that the whole tractor suspension implement has a slight steady trend as the tractor cultivate on the slope. It can be observed that under the condition of leveling, the center of gravity of the tractor suspension is displaced in the vertical direction. It changes linearly with time to maintain a constant trend, and the tractor body and the rear suspension implement can be in a horizontal state after leveling.

4. Conclusion

A tractor three degree of freedom of agricultural suspension implement model for studying the cultivate motions of mountain tractor has been presented above. The models related to the tractor body and suspension implement are prepared and solved in AME software and the solutions are imported. Corresponding simulation diagram of the mountain tractor suspension implements is analyzed. At the
same time, the relationship between the tractor suspension implement displacement and the leveling cylinder force is verified. The dynamic performance and profiled characteristic of the mountain tractor suspension implement have been presented well, which would be useful in the future to enhance tractor stability and slope cultivation depth safety.

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