

Construction of Support System for Suspension and Steering Layout of ATV

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ABSTRACT

When designing All-Terrain Vehicle (ATV) suspension and steering, over 40 different items should be verified in the layout stage, such as the change in geometry when the vehicle attitude changes due to wheel stroke, and the swing angle of each joint. Thus far it has been necessary to use multiple tools depending on the item to be verified, which has hindered the efficient investigation of specifications. Therefore, a system that enables verification in conjunction with the CAD layout was constructed by integrating the layout support tool and the mechanical analysis function built into CAD. In addition, rubber part deformation when the vehicle attitude changes is calculated using the nonlinear analysis built into CAD, enabling verification of the clearance that takes into account rubber part deformation. This enhances the layout accuracy and reduces man-hours when designing ATV suspension and steering.

1. Introduction

The suspension and steering of an All-Terrain Vehicle (ATV)⁽¹⁾ is a complex assembly of parts that swings, so it is challenging to investigate the effects of vehicle attitude changes due to wheel stroke in the layout stage. For this reason, ATV designers thus far have verified the effects of vehicle attitude changes using multiple tools for individual purposes, and then reflected these results to the layout.

With the popularization of 3D CAD in recent years, tools that can perform mechanical analysis and nonlinear analysis for calculating items such as rubber part deformation in 3D CAD have appeared on the market, and designers are able to investigate an increasing range of items by themselves.

This development integrates multiple verification functions used thus far by ATV designers into a 3D CAD tool, incorporates advanced CAE technology into a verification tool, and reports the resulting enhancement in layout verification efficiency and accuracy.

2. Features of ATV Suspension and Steering Layout

As shown in Fig. 1, the typical ATV suspension and steering has a structure similar to that of a passenger car⁽²⁾. However, it also has the following features for

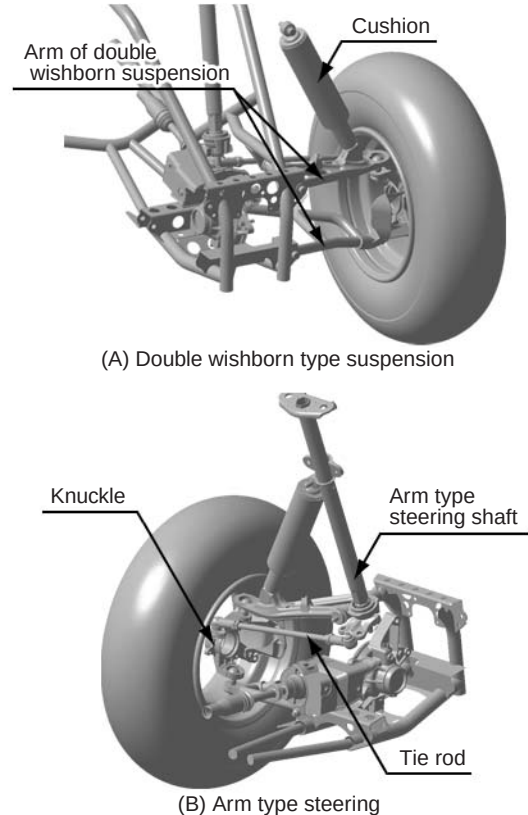


Fig. 1 Structures of assembled ATV suspension and steering

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applications such as sports running on dirt courses and carrying cargo on farm and ranch land.

- (1) The seating capacity is one person, and the tread width is approximately 1 m.
- (2) The tire camber angle, toe-in amount and other items vary greatly as shown in Fig. 2 to allow a large wheel stroke with a small suspension arm. In addition, the ball joint and arm pivot angles also vary greatly.
- (3) Center-arm-type steering is used, and a small steering angle produces a large tire turning angle.
- (4) The wheel radius is small, so the space around the wheel is narrow.

When developing an ATV, the layout needs to be investigated in consideration of these features.

3. Suspension and Steering Layout Issues

In an ATV suspension and steering layout, there are over 40 different items to verify, such as reducing changes in the geometry when the vehicle attitude changes due to wheel stroke, making sure that the swing angle of each joint does not exceed the operating limit, and securing clearance of the specified value or more. Issues when verifying these items in the layout stage are as follows.

- (1) Changes in vehicle attitude need to be verified using multiple calculation tools for different purposes, which has hindered the efficient investigation of specifications.

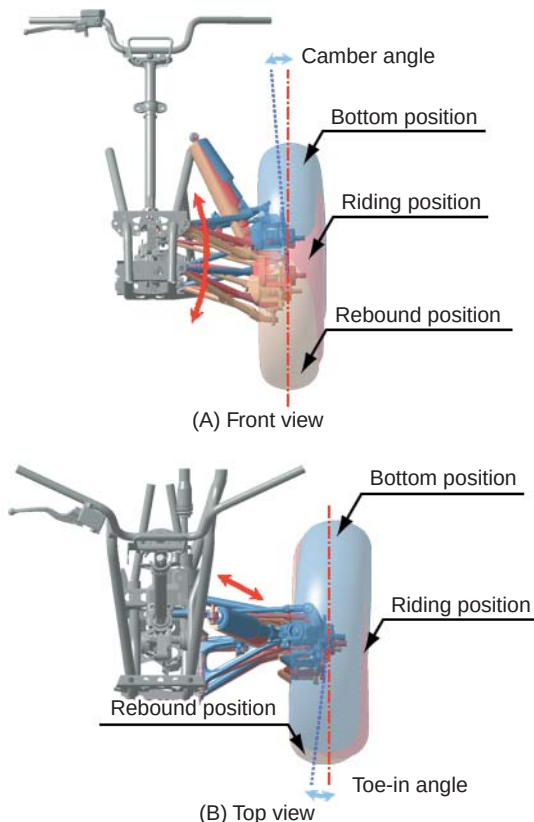


Fig. 2 Wheel stroke characteristics of wheel alignment

- (2) Tools thus far have offered only graph or numeric output of the change in camber angle or the joint swing angle during wheel stroke, and it was challenging for engineers to understand three-dimensional motion based on this data.
- (3) After the basic layout is determined, driving tests are conducted and the results are used to tune and adjust the toe-in and cushion lengths. However, it was challenging to accurately redraw the changed layout in CAD in order to reconfirm the verification items for the tuned layout.
- (4) The brake hose, rubber boot, and other rubber parts located around the suspension and steering undergo forcible bending and other deformation when the vehicle attitude changes. Nonlinear analysis is needed to investigate complex rubber deformation, but this entails the use of specialized technology, so application was limited.

4. Construction of an ATV Suspension and Steering Layout Support Tool

A tool was newly constructed that settles the issues noted in section 3 above. This tool enables calculation of changes in vehicle attitude and deformation of rubber parts around the suspension and steering on 3D CAD, allows designers to understand complex mechanical motion, and enhances layout accuracy. Figure 3 shows an outline of this tool.

4.1. Mechanical Analysis Models

A function was constructed that automatically creates a mechanical analysis model, such as that shown in Fig. 4. With this function, simply by selecting the ATV joint position in CAD, the change in vehicle attitude was

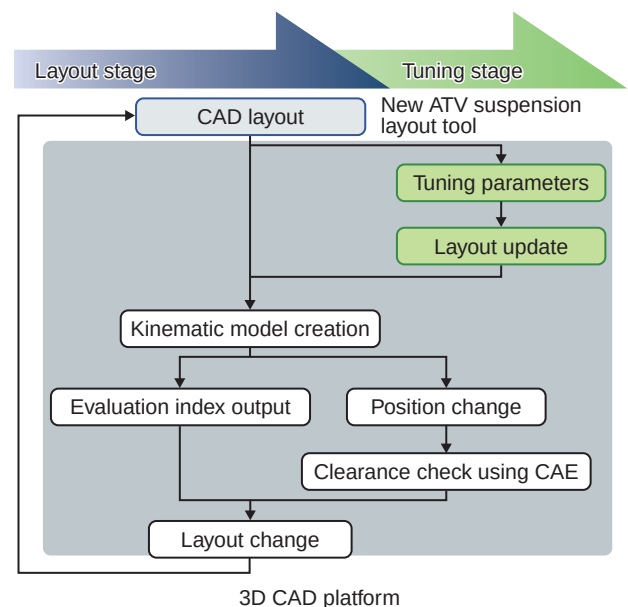


Fig. 3 Outline of new ATV suspension layout tool

calculated by using the mechanical analysis function built into 3D CAD. Automatic model creation is realized by preparing a basic mechanical analysis model for each ATV suspension and steering type, and reflecting the layout joint positions to these basic models.

The mechanical analysis models are created so that the vehicle attitude can be uniquely determined according to the wheel stroke and steering amounts. This is done by defining motion with limited degrees of translational and rotational freedom for the ball joints, rotating joints, and other joints at each joint position. This tool uses two mechanical analysis models: one for applications that calculate the change in vehicle attitude for an optional stroke amount, and one for applications that calculate the change in vehicle attitude for an optional steering amount.

• Model 1

Application: Calculating the vehicle attitude position for an optional wheel stroke amount, and calculating the cushion length for that attitude.

Configuration: This model defines a joint that restricts the vertical height from the ground-to-wheel center position to an optional value [Fig. 5(A)].

• Model 2

Application: Calculating the vehicle attitude position for an optional steering amount.

Configuration: This model defines a joint that restricts the cushion length to an optional value, and a joint that restricts the steering angle to an optional value [Fig. 5(B)].

Only model 1 is used to obtain the vehicle attitude change due to wheel stroke. When the attitude change by steering is obtained while restricting the vertical height of the wheel center using model 1, the cushion length changes unexpectedly. Therefore, the cushion length at the attitude obtained by model 1 is applied to model 2, and steering is performed while maintaining that cushion length.

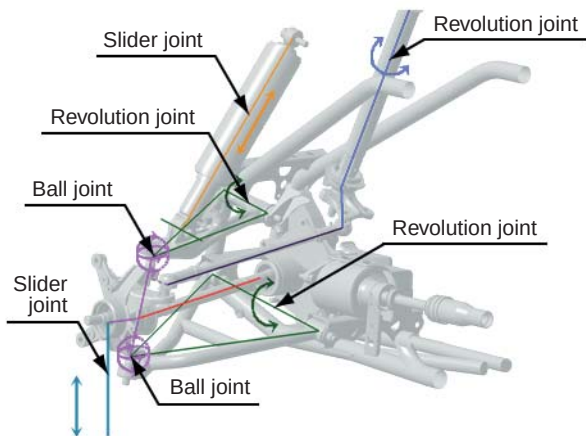


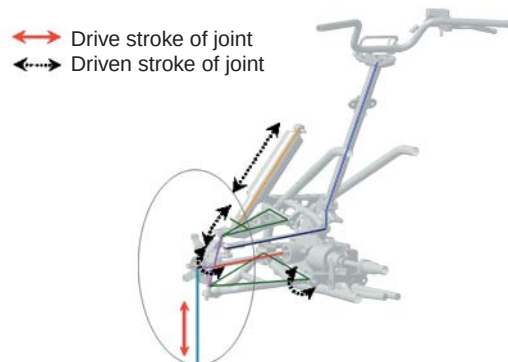
Fig. 4 ATV kinematics model

4.2. Calculation of Geometry

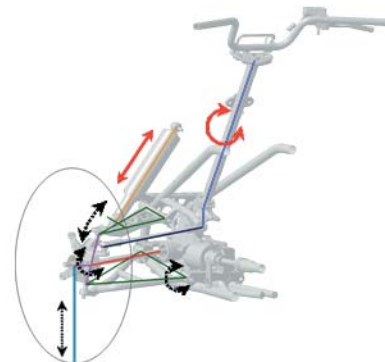
This tool recalculates and outputs the data in the form of characteristics graphs and evaluation values based on the main point coordinates of each part when the vehicle attitude changes within the mechanical analysis model. This enables evaluation of verification items such as the camber angle change and swing angle of each joint due to wheel stroke.

The geometric verification items include values that cannot be calculated as a simple angle in CAD, so these evaluation values are recalculated from the part position coordinates, and the following processing is performed by programs other than CAD.

- (1) When both the front and rear wheels are in contact with the ground, the vehicle attitude is tilted forward by 3° relative to the CAD layout, so the CAD coordinate values are converted to a coordinate system that uses the ground surface as the reference before calculating the evaluation values.
- (2) When the camber angle and toe-in angle are calculated from the coordinates at the top, bottom, front and rear edges on the tire outer, knuckle rotation around the wheel axis due to wheel stroke cannot be taken into account. Therefore, these angles are calculated from the coordinates of a reference point on the wheel center axis that is not influenced by rotation.
- (3) The swing angle clearance, until the ball joints at both



(A) Wheel stroke control kinematics model



(B) Cushion stroke control kinematics model

Fig. 5 Selection of ATV kinematics models

ends of the tie rod reach the operating limits when the vehicle attitude changes, is verified by the following method. Here, the side of the ball joint that swings is called the shank, the side that is fixed to the tie rod is called the housing, and the respective reference axes are defined as shown in Fig. 6(A). The torsional angle $\delta_{2(Limit)}$ at which the tie rod rotates on the central axis until the shank axis reaches the operating limit position at each vehicle attitude position is calculated by the following equations. Here, the swing range of shank axis is inside the cone, the radius of which (generating line) is “1”, and the vertex angle is the ball joint operating limit angle γ as shown in Fig. 6(B).

$$y = 1 \times \sin \delta_1, z = 1 \times \cos \gamma \quad (1)$$

$$x = \sqrt{\sin^2 \gamma - y^2} = \sqrt{\sin^2 \gamma - \sin^2 \delta_1} \quad (2)$$

$$\begin{aligned} \delta_{2(Limit)} &= \tan^{-1} \left(\frac{x}{z} \right) \\ &= \tan^{-1} \left(\frac{\sqrt{\sin^2 \gamma - \sin^2 \delta_1}}{\cos \gamma} \right) \end{aligned} \quad (3)$$

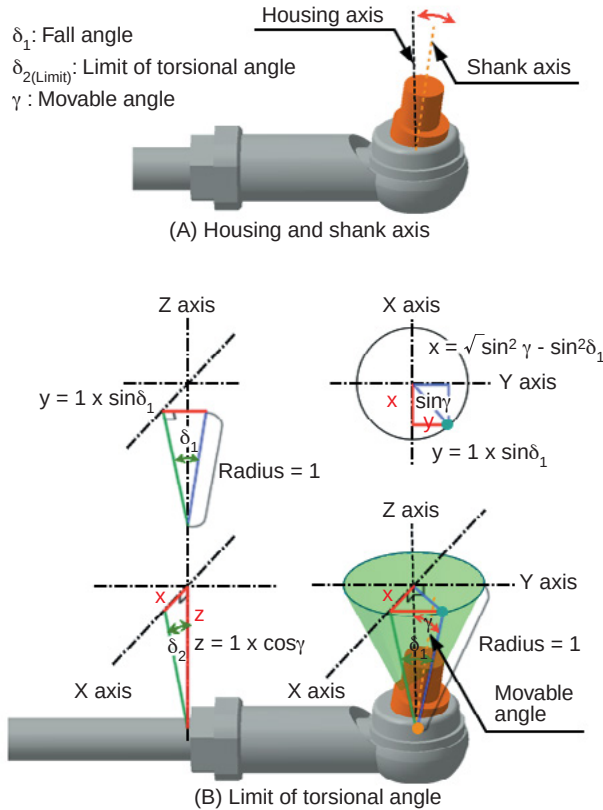


Fig. 6 Ball joint moving angle

y axis: Tie rod axis direction

z axis: Ball joint housing reference axis direction

γ : Ball joint swing operating limit angle

δ_1 : Fall angle by which the shank shaft tilts from the Z axis towards the y axis at each vehicle attitude position

δ_2 : Torsional angle by which the shank shaft rotates on the tie rod central axis (towards the x axis) from the z axis at each vehicle attitude position

- (4) In addition to the swing angle of the shank shaft on one side described in (3) above, the relative angle of the housing at both ends, as viewed from the tie rod axis direction, determines the clearance angle until the operating limit is reached. This relative angle is determined as the angle when the lock nut is tightened in the position with the tie rod twisted completely toward the front of the vehicle as shown in Fig. 7, in the vehicle attitude at the fully extended wheel stroke. Therefore, this angle was calculated by obtaining the torsional angle limits from the positions of the ball joints on both ends in the vehicle attitude at the fully extended wheel stroke.

In addition, when outputting the verification item calculation results, the layout information of each joint position and calculation results are registered in the tool, allowing to accumulate past layout information and overlay characteristics graphs to compare different layout specifications.

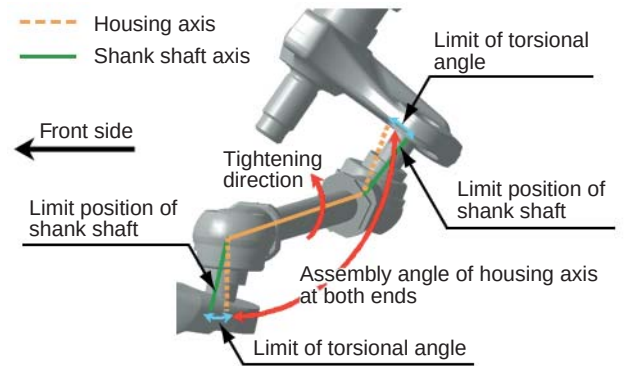


Fig. 7 Assembly angle of housing axis at both ends

4.3. Verification of Layout after Tuning

After driving tests, the layout is tuned by changing the tie rod length with the lock nut tightening position to adjust the toe-in amount, and by replacing the cushion to adjust the wheel stroke characteristics. The shapes of parts other than the tie rod and the cushion do not change, but each part is assembled via the joints, so the layout positions of other parts also change. Formerly, the layout had to be redrawn in CAD to reconfirm the verification items in the changed layout, but it was challenging to accurately obtain the position of each part that moved in

a three-dimensional manner. Therefore, a function was constructed that automatically obtains the layout position of each part, after tuning, simply by inputting numerical values of the toe-in amount and cushion length used for tuning.

To obtain the layout position of each part changed by tuning, translational joints that expand and contract the cushion and tie rod were incorporated into the mechanical analysis model that calculates vehicle attitude changes. First, the translational joint incorporated into the cushion is changed to the input cushion length by expanding and contracting. The translational joint that is incorporated into the tie rod is then adjusted in small increments so that the toe-in amount matches the input value. This translation joint adjustment process is repeated until the difference converges. This function enables the layout positions of other parts that are affected to be quickly and accurately ascertained when the toe-in amount and the cushion length change.

This tool has a special screen that obtains the layout positions after tuning by inputting the changed toe-in amount and cushion length based on the basic layout positions.

4.4. Verification of Clearance when Rubber Parts Deform

When evaluating the clearance between parts when the vehicle attitude changes, it is necessary to take into account how the brake hose, rubber boot, and other rubber parts located around the suspension and steering deform when the vehicle attitude changes. Thus far, rubber part deformation has been calculated by full-time analysts. However, a function was developed that calculates this deformation using the nonlinear analysis built into CAD, allowing designers to verify deformation at all vehicle attitudes.

Brake hose deformation is obtained by defining the hose end and clamp positions at the reference vehicle attitude, and then using the mechanical analysis model to calculate the hose end and clamp positions when the vehicle attitude changes by wheel stroke. The brake hose deformation at that vehicle attitude is calculated by nonlinear analysis, and the results are output as a CAD shape (Fig. 8). This function enables the CAD layout accuracy to be enhanced, such as by investigating clamp positions that can secure the necessary clearance.

Rubber boot deformation is obtained by reading the bend angle of the assembled joint when the vehicle attitude changes, calculating the deformed shape by applying this bend angle and the boot mounting location as conditions to the nonlinear analysis, and using these calculation results to create the CAD shape after deformation (Fig. 9). This calculation can reproduce the condition whereby the bellow ridges of the boot contact each other and bulge outward at large bend angles. Even complex deformation such as this could be reproduced to within an accuracy of approximately ± 3 mm.

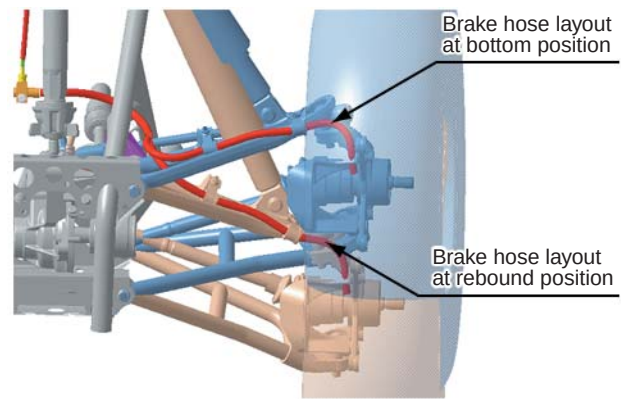


Fig. 8 Clearance with brake hose

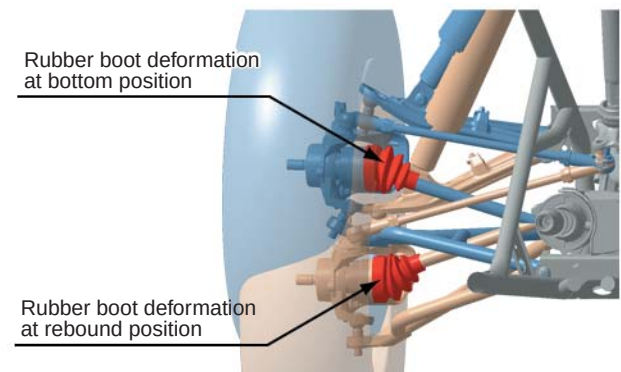


Fig. 9 Clearance with rubber boot

5. Effects of Application

Functions for calculating the suspension and steering geometry when the vehicle attitude changes were integrated, and functions for automatically calculating layout changes after tuning were combined into a tool. This reduced the man-hours needed to investigate suspension and steering layout specifications to 1/4 those of the previous level.

In addition, thus far layouts were investigated using only graphs and numeric results, but this tool enables 3D visual confirmation of conditions when the vehicle attitude changes, enabling investigation of complex mechanical motion.

Designers can also verify the clearance between parts, taking into account the rubber part deformation when the vehicle attitude changes.

6. Conclusion

A tool was constructed to evaluate verification items when ATV designers investigate suspension and steering layout specifications, and the following functions were realized.

- (1) Functions for evaluating verification items were integrated into a tool that uses 3D CAD mechanical analysis. This allows designers to understand the complex mechanical motion in three dimensions in conjunction with the CAD layout, and reduces the man-hours needed to investigate layout specifications to 1/4 those of the previous level.
- (2) The position of each part in the changed layout can be quickly and accurately calculated using mechanical analysis models in order to evaluate the layout after tuning by driving tests.
- (3) The deformation of the brake hose, rubber boot, and other rubber parts when the vehicle attitude changes can be calculated using the nonlinear analysis built into CAD, enabling verification of the clearance with surrounding parts.

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