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Design of a double wishbone front suspension for an orchard–vineyard tractor: Kinematic analysis

Stefano Uberti [a,*], Marco Gadola [a], Daniel Chindamo [a], Matteo Romano [a], Francesco Galli [b]

[a] *Università degli studi di Brescia – DIMI, Via Branze 38, 25123 Brescia, Italy*

[b] *SAME – Deutz Fahr SpA, Viale F. Cassani, 15, 24047 Treviglio, Bergamo, Italy*

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Abstract

This paper deals with the design and implementation of a double wishbone front suspension for a vineyard–orchard tractor, developed in conjunction with a major tractor brand.

To date, independent front suspensions are only found on commercial tractors over 150 kW. A front suspended axle is recognized as a popular option in improving tractor ride performance on larger vehicles. Despite their narrow track, vineyard–orchard tractors are required to have good lateral stability and stability on slopes (i.e. at least 28° rollover angle) and an extremely tight turning diameter for a 4WD vehicle (less than 7 m).

The discussion is concered with retrofitting an existing vehicle with a double wishbone front suspension.

This paper focuses on the layout and kinematic analysis phases of the design process. These were conducted in collaboration with the vehicle manufacturer to demonstrate suspension feasibility in terms of available space and correct kinematic layout.

The final kinematic turning diameter obtained is about 6.4 m, with a ±65 mm suspension travel available. The roll centre height value is not very sensitive to steering (about −95 mm excursion in the Z axis from no-steer position to full steer).

Keywords: Narrow-track tractor; Front axle independent suspension; Suspension design; Double wishbone suspension

1. Introduction

The present case study deals with an orchard/vineyard narrow-track tractor front suspension. It is well known that vineyard/orchard tractors are a class of agricultural vehicles that have to fulfil various specific tasks on different terrains. Their layouts are dictated by real world applications such as row cultures spacing. They must have a suitable narrow-track to allow them to pass between rows, tight turning capabilities (steering radius between walls less than 3.5 m) in order to perform manoeuvres at the end of each row, and high lateral/turning stability, since a large amount of farming sites are located on hill terrains or mountain regions.

Fig. 1 illustrates two typical layouts of a current non suspended vehicle of that class. On the left, an orchard tractor with wide front and rear track, large offset wheel rims and big front tyres, designed to operate in fruit cultivations with 1.4 m or larger row spacing and general purpose service. On the right, a different vehicle configuration based on the same vehicle chassis is shown, defined as "vineyard". It features narrower front and rear tracks, smaller front wheels (to allow for larger steering angles and tighter cornering radius), smaller rim offset, to enable operations in tightly spaced cultivation rows (1.4 m spacing or narrower). To date, there are no applications of full independent front suspension for such a tractor. Vineyard

* Corresponding author.

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Nomenclature

RC	roll centre
CoG	centre of gravity
x	longitudinal direction – positive backward
y	lateral direction – positive rightward
z	upright direction – positive upward
DOF	degree of freedom
DOR	degree of restraint
% Ack	Ackermann correctness percentage
α_i	internal wheel real steering angle
α_e	external wheel real steering angle
α_{ic}	internal wheel steering angle, corrected in regard to external wheel, to obtain ideal kinematic steering
α_{ec}	external wheel steering angle, corrected in regard to internal wheel, to obtain ideal kinematic steering
α_{icm}	internal wheel steering angle, corrected to have Rm as kinematic turning radius of rear axle midpoint
α_{ecm}	external wheel steering angle, corrected to have Rm as kinematic turning radius of rear axle midpoint
Tf	front track
Wb	wheelbase
R_i	rear axle midpoint turning radius, with correction of internal wheel angle in regard to internal wheel angle
R_e	rear axle midpoint turning radius, with correction of external wheel angle in regard to internal wheel angle
R_m	rear axle midpoint turning radius, considering mean value of front wheels axis projection on rear axle
τ	suspension motion ratio
TCR	rear axle midpoint kinematic turning radius
IC	instantaneous centre
F Tire	front Tire dimensions
R Tire	rear tire dimensions
Ra	front wheel index radius
Rp	rear wheel index radius
a	front overhang
b	rear overhang
W_r	rear width
W_f	front width
GC	vehicle ground clearance
D_{ff}	flange to flange distance (front axle)
Hp	pivot point height
FO	front overhang
RO	rear overhang
a	roll centre height, vehicle with non suspended axle
b	roll centre-centre of gravity distance, vehicle with non suspended axle
c	centre of gravity height, vehicle with non suspended axle
a'	roll centre height, vehicle with high pivoted non suspended axle
b'	roll centre-centre of gravity distance, vehicle with non suspended high pivoted axle
c'	centre of gravity height, vehicle with non suspended high pivoted axle
JF_{cp}	jacking force, vehicle with non suspended axle
JF_{hp}	jacking force, vehicle with non suspended high pivoted axle
F side force	one side lateral force

tractors have a flange-to-flange width around 1100 mm, while in orchard machines it is about 1300 mm. The definition of narrow-track machine is debated by Molari and Rondelli (2010) in relation with safety issues – roll over.

The above requirements force manufacturer engineers and researchers to face critical problems when designing an independent suspension, due to lack of available space.

While the topic of introducing tractor front axle suspension has been thoroughly investigated since the 60's, it has only been implemented in the form of a suspended live axle (sometimes also called a solid or beam axle). Only few cases of front full independent suspension are known to date and are limited to row crop machines.

Operator comfort has become a key factor in tractor business, starting from "high end" machines and gradually extending to smaller models (Matthews, 1967; Rill et al., 1992). This aspect has been also institutionally recognized and led to prescriptive and preventive actions, e.g. "*Good practices in agriculture: social partners participation in the prevention of musculoskeletal disorders*", funded by the European Commission (Agri-ergonomics.eu).

The SAE axis system has been used as a reference in this paper (see Fig. 2). For the purpose of the present work, the origin point has been set on the centreline of the vehicle, on the front axle ground projection.

In this market segment, typical tractors feature a rear rigid axle coupled with a non suspended tilting front axle (see Fig. 1), which allows for good traction performance, weight distribution in turning and stability over lateral slopes. The only vineyard suspended tractor features a live axle with torque tube and transverse reaction bar layout (Fig. 3 left), being torque tube and axle rigidly linked together. This layout imposes a high engine and hood position to allow for vertical suspension travel space (Ref. Fendt model 200V). This vehicle has been considered as a benchmark for this work.

Independent suspension could be an alternative way to realize suspension without sacrificing front vehicle height.