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CONSIDERATIONS ON THE SUSPENSION SYSTEM COMPONENTS OF AGRICULTURAL TRACTORS

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ABSTRACT: Drivers of agricultural tractors are subjected to a high level of mechanical vibrations caused by the working conditions specific for agricultural works. Sometimes, in the peak season, due too many hours spent driving the tractor on the agricultural field, drivers experience health related issues - usually back pain, lumbar discomfort and acute fatigue. To reduce the overall effects of tractor's vibrations on the driver's side, manufacturers use active, passive or hybrid suspension systems for the tractor's chassis only or in combination with seat and cabin suspensions.

Keywords: suspension system, agricultural tractor, closed loop control

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1. INTRODUCTION

Suspension systems generally used on agricultural tractors structure offer an increased comfort degree to the driver, improving in the same time vehicle's stability especially when turning. Tractor's stability depends on suspension system characteristics, main important aspects being the capacity to maintain a permanent contact between road's surface and tractor's wheels and to protect road's surface against damages caused by excessive forces exerted by tires.

Suspension systems for agricultural tractors consist of four suspension modules placed at each one of tractor's corners, connecting tractor's chassis to its wheels. Every suspension module is made of a spring-damper unit, connected in parallel – also known as a passive suspension system. This type of module can be simulated numerically using the Kelvin-Voigt model. There is known and used the concept of active suspension systems that consists of the same two parallel spring-damper elements, but some of their working parameters can be adjusted through electronic, hydraulic or pneumatic driving signals. Although active suspension systems can be programmed to function as passive ones (similar characteristics), the issue is to achieve better comfort and handling of the agricultural tractor using closed loop control.

Passive suspension systems use steel springs and hydraulic dampers, but due to mechanical wear, in normal working cycles, their functional parameters vary in time leading to poor driver comfort and vehicle stability. In fact, an ideal suspension system must provide at the same time both maximal comfort and stability, but in practice a good suspension system is a compromise between comfort and stability. Driver comfort is left on a second side when designing a suspension system because vehicle's stability is a critical safety issue and the manufacturers always put it first.

When dealing with vehicle stability we are dealing with a sum of variables, most important being: resistance forces against chassis movements, weight transfer factor from back to front of the chassis, amplitude of tires vibrations in vertical plane, road's surface unevenness, centrifugal forces when turning and tire-road contact forces. Taking into consideration designing a passive suspension system for agricultural tractors, we encounter another issue because of the higher center of gravity, total weight and hard accelerations transmitted (through chassis) to the driver.

Another aspect to take into consideration is that agricultural works need sometimes a constant high speed, which adds another variable to suspension system design. All these conduct, in the first place, to lower vehicle stability.

Some agricultural tractor manufacturers consider that the rear tires are enough when dealing with suspension systems (because of their size), others have mounted a (relatively) stiff suspension on the front axle and some others use cabin active suspension in combination with driver seat suspension. Active suspension systems imply using electrohydraulic closed loop control, which – with the help of new technologies in electronics – can substantially improve driver comfort and vehicle's stability.

2. MATERIAL AND METHOD

Modern agricultural tractors manufacturers have adapted to their need some concepts already used in automotive industry, related to active suspensions. Classic parallel spring-damper structure has been upgraded to a similar structure using electronic controlled hydraulic actuators. This imply redesigning some of vehicle's components and linkage system.

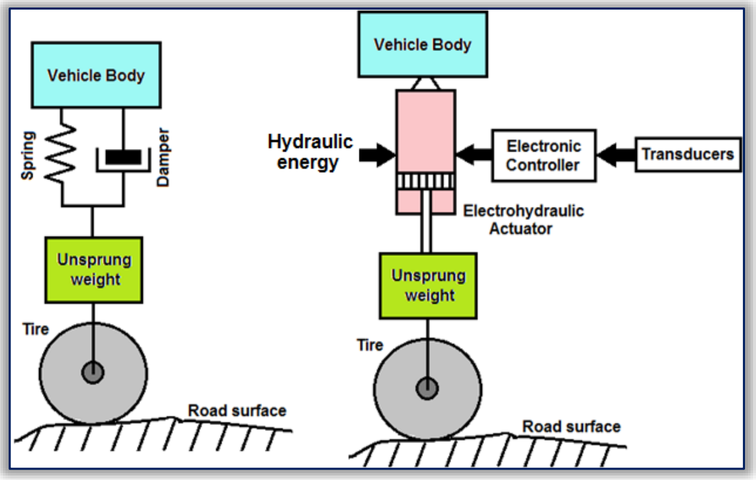


Figure 1. Schematic comparison between classic suspension system and active suspension system

A simple model of a passive suspension must take into consideration that the spring will store vibration energy and the damper will dissipate it, mechanical characteristics of the linkage system with vehicle's chassis, the unsprung weight (which is total weight of the suspension, wheel and components connected but not supported by the suspension) and the fact that the tire itself can be considered as a spring.

As it can be seen in Figure 1, classic parallel spring-damper module has been replaced by an electronic controlled electrohydraulic actuator (directional and auxiliary equipment have not been figured here). This new configuration offers programmable functional characteristics, having – in theory – unlimited performances in terms of vehicle stability and driver comfort, but – in real life – there are limited by mechanical constrains. Active suspension systems use closed loop control.

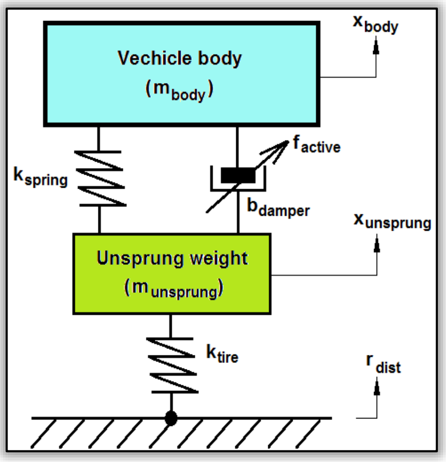


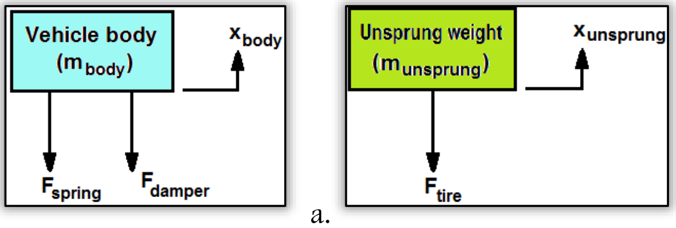
Figure 2. Equivalent model of an active suspension system

m_{body} – vehicle's body mass;
$m_{unsprung}$ – unsprung mass (including tire weight);
k_{spring} – spring compressibility;
b_{damper} – damper rigidity;
f_{active} – active component (actuator) force;
k_{tire} – pneumatic tire compressibility;
r_{dist} – road disturbance;
x_{body} – travel of vehicle's body;
$x_{unsprung}$ – travel of the unsprung mass.

First, we assume that:

$$x = 0 \text{ and } y = 0 \qquad (1)$$

meaning that the system is in static equilibrium, allowing that gravity can be neglected. Let consider that the springs and the damper have linear characteristics (considering that f_{active} is constant) and the damping coefficient of the tire is negligible. Therefore, the tire is represented in the model given in Figure 2 as a spring.



a. b.

Figure 3. Suspension system model breakdown

Considering Figure 3.a, mass m_{body} has a displacement of x_{body}; it must be defined two forces given by the spring and the damper:

$$F_{damper} = b(\dot{x}_{body} - \dot{x}_{unsprung}) \tag{2}$$

$$F_{spring} = k_{spring}(x_{body} - x_{unsprung}) \tag{3}$$

In Figure 3.b, mass $m_{unsprung}$ has a displacement of $x_{unsprung}$; it must be define one force given by the tire:

$$F_{tire} = k_{tire}(x_{unsprung} - r_{dist}) \tag{4}$$

It is a given fact that:

$$\sum F = m \cdot a \tag{5}$$

therefore, writing equation (5) for masses m_{body} and $m_{unsprung}$ we have:

$$\sum F_1 = -F_{spring} - F_{damper} = m_{body} \cdot \ddot{x}_{body} \tag{6}$$

$$\sum F_1 = -k_{spring}(x_{body} - x_{unsprung}) - b_{damper}(\dot{x}_{body} - \dot{x}_{unsprung}) = m_{body} \cdot \ddot{x}_{body} \tag{7}$$

$$\sum F_2 = F_{spring} + F_{damper} - F_{tire} = m_1 \cdot \ddot{x}_{unsprung} \tag{8}$$

$$\sum F_2 = k_{spring}(x_{body} - x_{unsprung}) + b_{damper}(\dot{x}_{body} - \dot{x}_{unsprung}) = m_{unsprung} \cdot \ddot{x}_{unsprung} \tag{9}$$

Considering the equations above (6) … (9), we have:

$$\begin{aligned} m_{unsprung} \cdot \ddot{x}_{unsprung} + b_{damper} \cdot \dot{x}_{unsprung} + (k_{tire} + k_{body}) \cdot x_{unsprung} = \\ = b_{damper} \cdot \dot{x}_{body} + k_{spring} \cdot x_{body} + k_{tire} \cdot r_{dist} \end{aligned} \tag{10}$$

and:

$$m_{body} \cdot \ddot{x}_{body} + b_{damper} \cdot \dot{x}_{body} + k_{spring} \cdot x_{body} = b_{damper} \cdot \dot{x}_{unsprung} + k_{spring} \cdot x_{unsprung} \tag{11}$$

3. RESULTS

Classic suspension system can only store and dissipate (when needed) vibration energy, while active suspensions have one more capability: to inject energy (when needed) into the system. Computing the injected energy amount and its opportunity is done usually by a microcontroller programme having as primary data the electronic signals given by system's transducers. The command computed by the microcontroller is applied to an electronic signal amplifier and afterwards applied (usually) to an electrohydraulic actuator.

The electronic controller used to regulate active suspension's behavior has a microcontroller as central processing unit, signal conditioning modules and signal amplifiers. The microcontroller is chosen according to hardware needs of a specific control algorithm, number of transducer inputs and number of driven actuators. In active suspension system control, the electronic controller algorithm has to take into account the entire range of frequencies of the system, trying to obtain an optimal control of mechanical vibrations providing in the same time driver comfort and vehicle stability. These all are leading to overall improved functionality, but it requires much more power than a classic suspension system, thus leading to increased fuel consumption and running costs.

Furthermore, active suspension systems require accurate control of working parameters and therefore needs fast electrohydraulic actuators and electro-valves. Active suspension's high degree of structural complexity require specialized personnel to undertake installation and maintenance procedures. Total running costs and maintenance costs in the case of active suspension systems are significantly higher than a classic suspension, which recommends them to be used only in special applications.

As active suspension systems have as main driving equipment an electrohydraulic actuator, it must be taken into consideration specific critical failure situations of the actuator itself, of the electronic controller board or even unexpected programming errors. In particular cases, all these can lead to dangerous or potential life-threatening situations. A mechanical spring and in some cases a parallel damper, is mounted in series with an active suspension system that can overcome this drawback. Passive suspension system will work as a "safety-buffer" when active suspension system encounters a failure, thus reducing the risk of potential dangerous functioning conditions. General response of the series (passive-active) suspension system it is designated to improve the dynamic response in the range of natural frequencies of vehicle's chassis.

Passive suspension systems proved to have good stability during braking, accelerating and turning of the vehicle, but the major gain over active suspension systems is lower energy use and that are known to reduce critical failure modes encountered in active suspension systems. Active suspensions have very good dynamic performances when referring to driver comfort and vehicle stability, but in general practice are not recommended to be used in heavy weight vehicle construction due to their high energy consumption.

4. CONCLUSIONS

Active suspension systems used in the field of agricultural tractors are in theory the best solution for compensating mechanical vibrations caused by agricultural road surface unevenness and normal functioning regime of a tractor: braking, accelerating and turning.

The major drawbacks of active suspension systems are high energy consumption, high running and maintenance costs, complexity of the suspension system with all the auxiliary equipment and high installation costs.

As a general guideline, hybrid solutions comprising an active and a passive suspension system are more likely to be used.

Note

This paper is based on the paper presented at ISB-INMA TEH' 2015 International Symposium (Agricultural and Mechanical Engineering), organized by „Politehnica" University of Bucharest - Faculty of Biotechnical Systems Engineering, National Institute of Research-Development for Machines and Installations Designed to Agriculture and Food Industry - INMA Bucharest, EurAgEng - European Society of Agricultural Engineers and Romanian Society of Agricultural Engineers - SIMAR, in Bucharest, ROMANIA, between 29 - 31 October, 2015, referred here as [6].

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