Active bogies, chassis levelling and transmission efficiency for a vehicle operating in rough terrain

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Abstract

There is a growing interest in developing systems that allow the mobility of vehicles in rugged terrain, as in forestry areas, where conventional wheeled vehicles have limitations.

Four axle vehicles with bogies can adapt the position of the wheels to follow irregularities in the terrain, having an obstacle surpassing ability far greater than conventional 2-axle vehicles. Still, the ability to overcome discrete obstacles on a steep slope is very different depending on the wheel that is facing the obstacle. A possible solution to diminish this variation can be found if the vehicle is able to actively redistribute the load on each wheel.

One strategy is to design the suspension mechanism so it can adjust chassis' height, being able to level it. Also, an active torque on the pin join between the bogie and the chassis can be applied achieving a redistribution of the load, adopting a system of active bogies.

This study examines the longitudinal motion of a vehicle along ascending ramps, with different slope, at the time that one of its wheels is facing an obstacle. Results for different vehicle's configurations are presented, and the efficiency of the proposed driveline is calculated in different situations.

Results show that the use of active bogies provides improved capacity to overcome obstacles, active chassis levelling can also provide an improvement in the obstacle surmounting ability. However, the wheels of the front bogie are negatively affected by the height regulation, so implementing a permanent chassis levelling is not the best solution. The driveline efficiency results are considerably lower than the combination of the maximum efficiency values of each of the components because they all never work simultaneously at their maximum efficiency working point. In addition, the overall driveline efficiency is highly dependant on the operating conditions of each of the elements and their operation mode.

Key words: off-road, traction, transmission, bogies, hydrostatic.

1. Introduction

Having vehicles with a higher capacity of overcoming obstacles can increase the available means to obtain larger amount of biomass and improve the conditions and efficiency of forest cleanup operations.

An alternative approach to the problem of adaptability in rough terrain is to seek a compromise between standard wheeled vehicles and vehicles with legs. There is a wide range of vehicle designs where position of the wheels can be adapted with respect to the chassis position, either by passive means (bogies and other mechanisms) or by the addition of an actively controlled degree of freedom (McCloskey, 2007). Although the traction is always limited by the wheels grip, its ability to overcome obstacles and to move over rough terrain is significantly increased compared to conventional vehicles.

Another common solution in the field of space exploration vehicles is the level adjustment of the vehicle's chassis through climbing and obstacle negotiation. These systems allow dynamically adjusting roll, pitch and chassis height (Yang & Li, 2006). The centre of mass reallocation provides enhanced stability (Bretl & Lall, 2008, Shiller & Mann, 2004) as well as better ground traction as it allows shifting the centre of gravity backwards and forwards (Grand et al., 2002, Iagnemma, 2000).

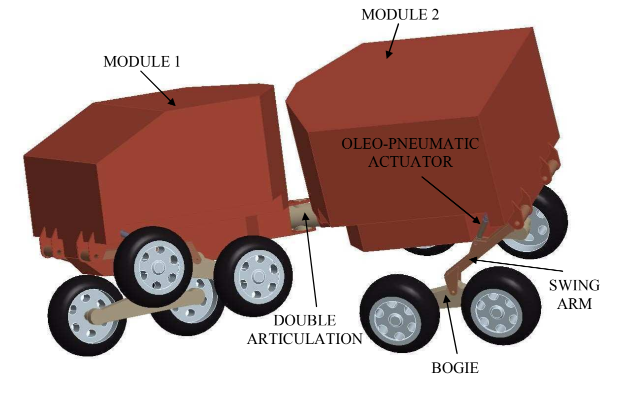
The aim of this study is to compare and analyze parametrically two active solutions in order to improve the capacity to overcome obstacles of vehicles with bogies. The effect of actively levelling the vehicle chassis as well as the effect of modifying the weight distribution by means of active bogies will be discussed.

Moreover, level adjustment technique requires large wheels displacement and for considerable load capacity vehicles' hydrostatic transmission in the driveline is often considered a better solution than the mechanical one. Few studies have been found focused on the interaction between components to analyse the efficiency of the whole driveline according to the operating conditions. Most of them have been carried out for the case of mechanical transmission (Yi et al., 2007).

An efficiency sensitivity analysis of the hydrostatic transmission in this type of vehicles has also been done, quantifying the power flow in each of the transmission elements and the overall performance of the whole vehicle driveline, as a function of its operating conditions.

2. Studied vehicle

This study is based on a vehicle consisting of 2 modules linked by a double articulation joint, with 8 wheels grouped in 4 bogie assemblies, 2 per module. The double articulation joint and the bogie mechanisms allow the 8 wheels to adapt their position in order to ensure the contact of all the wheels with the ground. In Fig. 1, a scheme of the vehicle is shown and the general specifications are summarized.



Variable	Value
Length	3600 mm
Width	1500 mm
Height	1800 mm
Wheel diameter	600 mm
Vehicle weight	1200 kg
Load Capacity	800 kg
Maximum weight	2000 kg
Maximum speed	30 km/h

FIGURE 1: Scheme and general specifications of the studied vehicle

3. Methodology

The longitudinal motion of the vehicle is analyzed. A bi-dimensional vehicle model has been considered for the kinematics and dynamic analysis. It is constituted by a multibody system. All-wheel drive is considered and no slippage has been assumed. Therefore the resulting system has been modelled as a multibody mechanism with one degree of freedom. The developed vehicle model allows imposing any approaching velocities and accelerations for the wheel facing an obstacle. However, the situations analyzed in this study are quasi-static. In this analysis rigid wheels and a Coulomb friction model for wheel-ground contact have been assumed. Also, the coefficient of friction between the wheels and the ground is assumed to be equal in all axles, and all the wheels reach the adherence limit situation simultaneously, so the ratio between tangential and normal forces at the contact point is assumed to be equal in all the wheels.

3.1. Active bogies

The vehicle along ascending ramps is analyzed at the time that one of its wheels is facing an obstacle that is modelled by an inclined contact surface. The study focuses on the possible improvement of the obstacle surmounting ability.

Increased capacity to overcome obstacles could be obtained by using active bogies. The active bogie system provides a reaction torque in the articulated joint that links each of the bogies to the swingarms (Fig. 2). The bogies are actuated so as to produce a variation of normal force distribution between the two wheel axles of the bogie and decreasing the load of the wheel facing an obstacle.

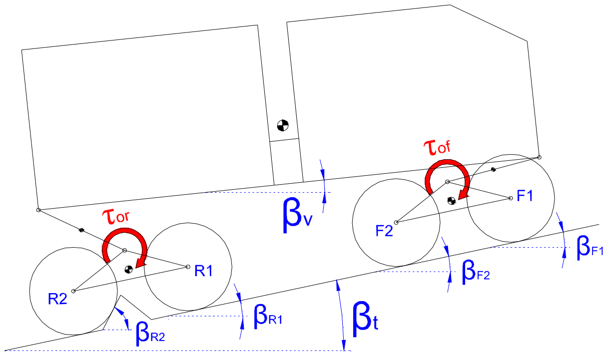


FIGURE 2: Active bogies actuation

3.2. Chassis levelling

Modifying the height between the chassis and the bogie could be another method to increase the capacity to overcome obstacles. This can be achieved by the inclusion of a swingarm between the vehicle chassis and the articulated joint of the bogie. The swingarms are articulated at the outer edges of the chassis. The levelling strategy has been lowering the front and raising the rear so that the swingarms reach its extreme positions simultaneously.

Two different strategies are studied (Fig. 3). In the half-levelling strategy, the levelling mechanism acts so that the angle of the chassis is maintained at half the terrain slopes whenever possible. In the full-levelling strategy, the levelling mechanism acts so that the chassis remains horizontal whenever possible, regardless of the terrain slope.

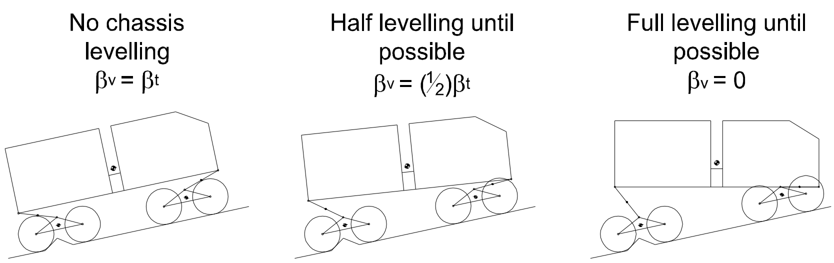


FIGURE 3: Chassis levelling strategies

3.3. Transmission

The power transmission efficiency from the engine to the wheels has been analysed as a function of the vehicle speed and terrains slope. The analysed transmission configuration comprises two hydraulic pumps, four hydraulic motors (one per bogie) and eight chain mechanisms. The hydraulic motors are placed on the bogie at the same distance between both corresponding wheels.

Two operation modes have been considered, regarding the connection between pumps and hydraulic motors. They can be selected in every situation depending on the operating requirements of the vehicle (Fig. 4).

• S.O.M. (Series Operation Mode): The output of both pumps are joined and the flow is directed to the group of 2 motors of the front module of the vehicle, and then to the group of 2 motors of the rear module. The 2 groups of motors are connected in series.

• P.O.M. (Parallel Operation Mode): Each pump is connected to a group of motors, so they define 2 independent circuits that operate in parallel.

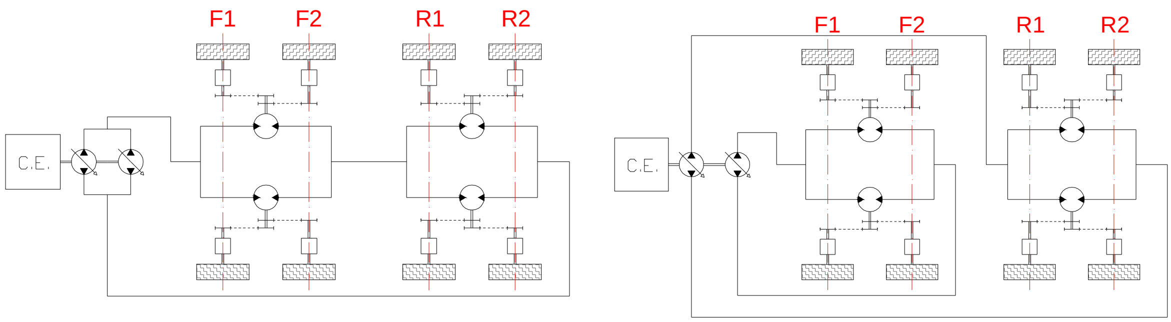


FIGURE 4: Layout of the configuration with the series operation mode (left) and the parallel operation mode (right)

4. Results

4.1. Obstacle surmounting ability

The objective of creating load redistribution with the active bogies or the chassis levelling is to increase the capacity to overcome obstacles. For the vehicle with active bogies, the results of applying different actuation torque in the rear bogie, when facing an obstacle in the limiting axle R2, can be seen in Fig. 5 (left). An improvement in the obstacle surmounting capacity is obtained in the whole range of ascending slopes β_t and for any friction coefficient μ between wheels and terrain. It has also been observed that the improvement is approximately proportional to the actuation torque for given values of β_t and μ. For a given friction coefficient, the obtained improvement decreases as β_t increases, and reaching zero when the vehicle is facing the maximum slope without obstacles.

The obstacle surmounting ability for the second most limiting axle, F2, has also been studied. The results are shown in Fig. 5 (right). It can be observed that there is a considerable improvement to be obtained when the front bogie is actuated. For a given actuation torque, this improvement is greater in percentage terms than for the R2 axle. However, in this case proportionality between actuation torque and the improvement obtained is not retained.

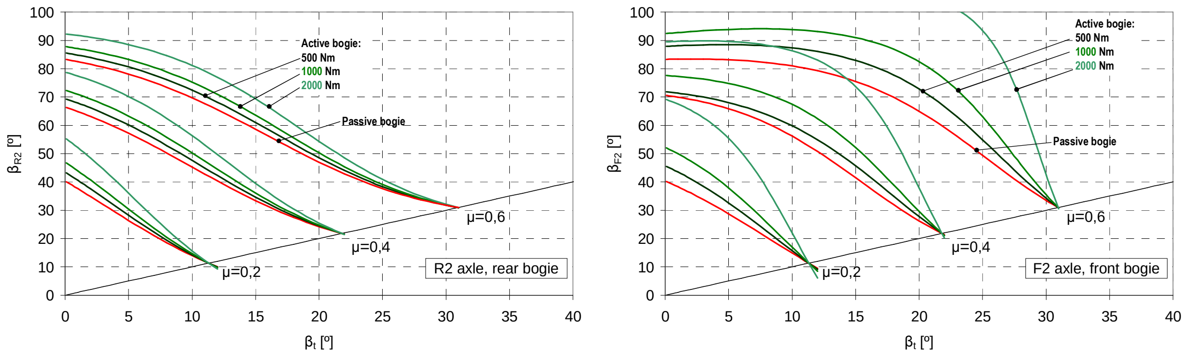


FIGURE 5: Effect of bogie actuation on the limiting axle R2 (left) and F2 (right)

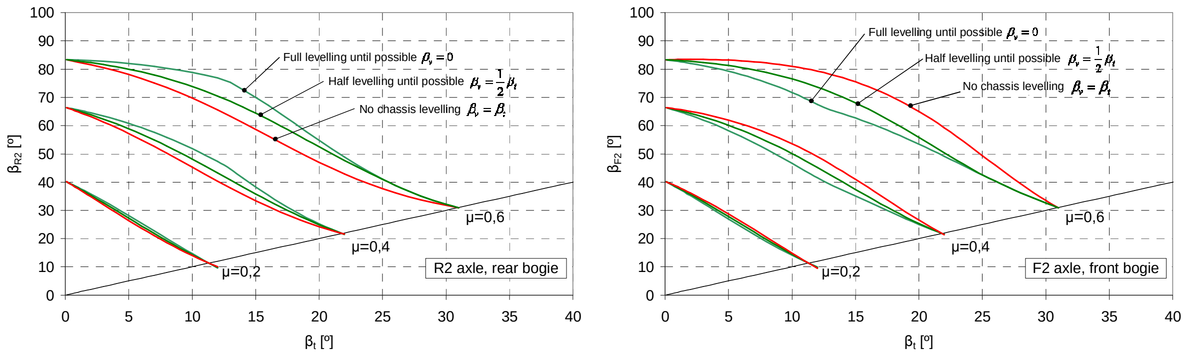


FIGURE 6: Effect of chassis levelling on the limiting axle R2 (left) and F2 (right)

The results for the vehicle with chassis height regulation have been analyzed (Fig. 6). The main difference compared to the vehicle with active bogies is that levelling the chassis, although increasing longitudinal stability worsens the ability of the F2 wheel to overcome obstacles. When compared to the vehicle without chassis height adjustment, the improvement increases from zero (when the terrain is horizontal) up to a maximum value and decreases again to be zero when β_t is the maximum angle for a given μ, with no obstacle.

4.2. Transmission efficiency

In Fig. 7 the transmission efficiency as a function of the vehicle speed for different terrain slopes is presented. It can be seen that at low speeds the efficiency is always higher in a parallel compared to a series operation mode regardless of the terrain slope. This is due to the fact that in the parallel mode the hydraulic circuits of each vehicle's modules operate independently (as far as flow and pressure concerns), which allows the maximum circuit pressure to be lower. In both operation modes (series and parallel) the circulating flow through the motors when the vehicle moves at a certain speed is almost the same, as the speed is also the same. However, in a series operation mode the pressure has to be higher to reach the required torques in each of the axles and it decreases in cascade from its maximum value at the inlet of the first group of motors to the suction pressure before the pump inlet.

As the vehicle runs at a low speed, there is a low flow rate and its influence in losses is lower. When the vehicle speed increases and the required torque conditions are maintained, the losses due to the high flow have a greater importance. While the flow is almost the same in the motors, the flow in the pumps doubles in the P.O.M. In a parallel operation mode it is not possible to reach the whole vehicle speed range because the maximum pump displacement limits the output flow. In P.O.M., the maximum attainable speed decreases as the terrain slope gets higher. The reason is that for higher slopes higher pressure is needed, and then it leads to greater flow losses (leakage flow, both in pumps and motors) and a reduction of the effective flow. In the series operation mode, the limiting aspect is the maximum pressure reached in the circuit. That is why cases with a terrain slope higher than 20º are not technically feasible with this operation mode. For high speed and high slope simultaneously is not possible to reach the maximum specified speed of 30 km/h. The maximum power for the hydraulic motors is exceeded.

It is important to notice that the global transmission efficiency is very variable depending on the operating conditions, and its maximum value for a given slope can range between a 25% when the vehicle runs in a flat terrain to 70% in maximum slopes.

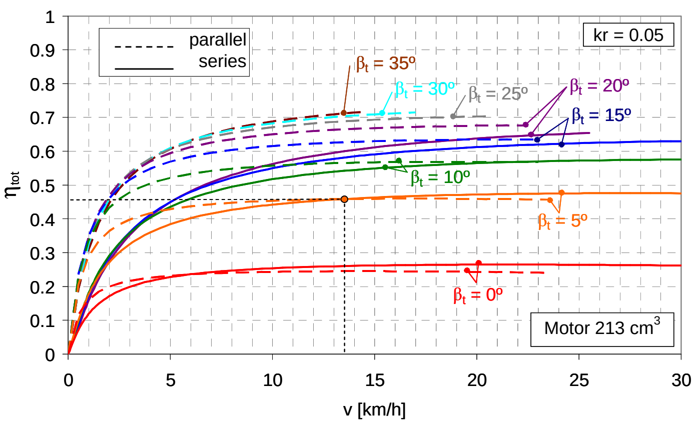


FIGURE 7: Efficiency as a function of vehicle speed and terrain slope

It can be appreciated that the global transmission efficiency is null when the speed is 0 km/h, as there is no output power, and that for low speeds the global efficiency is very low as it is necessary to overcome the no load losses and the output power is low. The efficiency increases rapidly when the vehicle speed rises as the output power also increases. That happens from 0 to around 5 km/h, thereafter the influence of the speed increase is not as significant. It can be observed that in some of the studied scenarios there is a speed from which the efficiency line takes a slightly negative slope value. This is the speed at which the losses caused by the speed increase begin to be higher than the output power increase.

5. Conclusions

Different results have shown the improvement in obstacle surpassing ability obtained by the use of active bogies and height regulation. The use of active bogies provides improved capacity to overcome obstacles in the full range of ascending slopes. This improvement is manifested in all axles of the vehicle and with any coefficient of friction between wheel and terrain. On the other hand, active chassis levelling can also provide an improvement in the obstacle surmounting ability, in addition to enhanced stability. However, the wheels of the front bogie are negatively affected by the height regulation, so implementing a permanent chassis levelling is not the best solution.

The efficiency results obtained for the whole transmission are considerably lower than the combination of the maximum efficiency values of each of the components that make up the driveline. It is demonstrated that combining different components decreases the overall performance because they all never work simultaneously at their maximum efficiency working point. It is verified that the overall driveline efficiency depends on the operating conditions, the relationship between elements and their operation mode (series or parallel). At low slopes, very low efficiencies are obtained because the transmission components are far from their optimal operating point.

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