

Load Estimation of an Open-Link Locomotion Module for Robotic and Commercial Multi-Wheel Applications

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ABSTRACT

An open-link locomotion module, comprising a driving wheel with an electric motor, a system of electro-hydraulic suspension, and an electro-hydraulic power steering system, is presented in this paper as the basis for the modular design of unmanned (robotic) ground vehicles. The open-link-type configuration allows the module to be functionally integrated and engineered with a system of similar modules and thus virtually allows to compile vehicles with any required number of driving wheels. The overall dimensions and carrying capacity of the tire used in the module, as well as technical characteristics of the suspension and power steering systems make possible to employ the module for commercial ground vehicle applications.

This paper considers technical issues related to designing the locomotion module. In particular, the interaction of the suspension and steering systems is studied while the systems form the normal reaction of the wheel and influence the resistance moment in the tire-road contact patch. The suspension characteristics influence the wheel normal reaction, tire deflections, and the over roll area of the tire patch. An increased tire patch area has a positive effect on stability of motion of the module and the vehicle as a whole. However, friction in the tire-road contact also goes up and increases power losses to steer the wheel. This can degrade module and vehicle handling performance.

Theoretical and experimental studies (conducted on a test bench and a real automobile built from a set of the locomotion modules) have shown that the problem of increasing stability on motion and improving handling performance of the module can be solved by (i) defining and determining the friction/resistance moment of the tire as a function of the normal reaction of the wheel; (ii) computing the pressure of the working liquid p_r in the electro-hydraulic power steering system that is sufficient to overcome the resistance moment; and (iii) by means of functional fusion of the suspension and steering control systems, in which stiffness and damping characteristics are controlled and thus generate a tire patch, which ensures the preset characteristics of module stability and handling. In addition, ride smoothness requirements are also observed.

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INTRODUCTION

Technical issues of increasing stability of motion and at the same time improving vehicle handling were always under consideration in vehicle dynamics [1, 2, 3, 4, 5, 6]. Available solutions resulted in active suspension systems [6, 7] and active steering systems [8]. An active steering system of the

front wheels is, for example, a rather new technology that can be integrated with an automatically controlled suspension. The work [9] considers these issues together with functional safety problems. In paper [10], an integration of control systems of active steering, active suspension, and active braking is presented.

The conceptual design layout of the suspension system of the open-link locomotion module is presented in [Figure 3](#). The suspension varies its energy intensity at the compression and rebound strokes and thus changes the position of the piston of the power cylinder at a constant static load on the elastic suspension element. The adjustable shock-absorber ensures a broad range of dynamic characteristics of the elastic and damping elements of the suspension. To damp oscillations in the suspension, double-sided adjustable hydraulic shock-absorbers 1, 2 and 14, see [Figure 3](#), are used. A resilient-damping element comprises a working hydraulic cylinder 14, a pneumatic-hydraulic accumulator 5 and 12, counter-pressure containers 6 and 13, throttles with regulated liquid flow rate 4 and 11, electric valves (electro-hydraulic distributors) with pressure sensors 7, 8 and 9. A system of sensors 1-4 and 7-9 permanently monitors the pressure dynamics of the working liquids in the system. This information is processed by the suspension controller and is converted into a signal, which is then sent to the ACS controller and then finally turns into a steered angle value. More detail on the design and operation of the suspension system is given in [6].

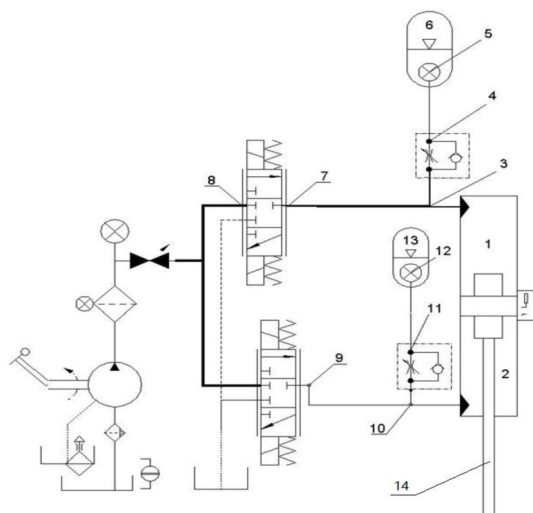


Figure 3. Diagram of the controlled system of the wheel springing with a pneumatic-hydraulic resilient element (a key is given in text)

Thus, the tire normal reaction is determined and then its value is used in the steering system of the module for computing the resistance moment and the pressure in the hydraulic cylinder 6 of the steering system (see the diagram of this system in Figure 4).

An electrohydraulic drive with a volumetric fluid flow rate control was chosen as the individual steering system of the locomotion module (Figure 4). The backlash of the drive mechanism, its stiffness, and non-linear kinematics of the mechanical and hydraulic components were included in the mathematical modeling. Computational fluid dynamics methods were used for modeling hydraulic components.

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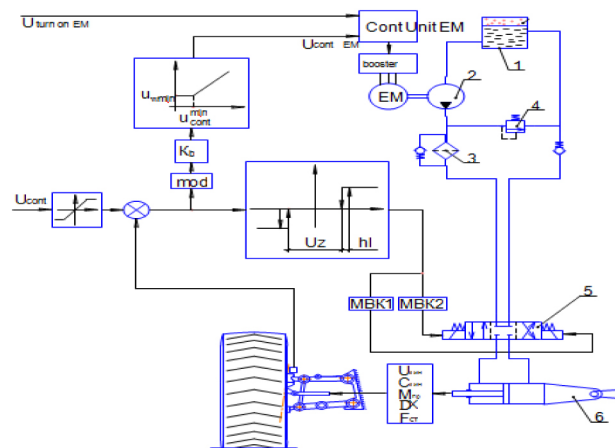


Figure 4. The basic diagram of a steered wheel with an autonomous electrohydraulic steering drive with the volumetric regulation of the fluid flow rate: Hydraulic components: 1 - a hydraulic tank; 2 - a non-regulated, non-reversible pump; 3 - a filter; 4 - a safety valve; 5 - a three-way valve; 6 - a hydraulic cylinder. Signals of the control system: U_{cont} - signal that sets the wheel turning angle; U_{contEM} - signal that sets the rotation frequency of the electric motor (angular wheel turning velocity); U_{ang} - signal about the real wheel turning angle; $U_b = U_{contEM}/(U_{cont} - U_{ang})$ - the boosting coefficient; $U_{\omega min}$ - setting of the minimum rotation rate of the electric motor; U_z - dead zone of the distributor; h_1 - width of the hysteresis loop.

As was specified before, the interaction of the suspension and steering systems, shown in Figures 3 and, should be studied, and the tire-road interaction is the place for doing this; results of the study are presented below.

Tire-Road Friction Moment

A constraint equation that is imposed on the math models of the suspension and steering systems is the equation of the moment of forces M_{Σ} , which is reduced to the wheel steering axis formed by the tire-road interaction. Typically, this factor is ignored in passenger car simulations, since it has an insignificant effect on the change of the position of the vehicle body in space. However, in case of off-road tires