

Autonomous Mechatronics-Based Locomotion Module for Multi-Wheel Vehicle and Terrestrial Robot Applications

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ABSTRACT

The main trend in designs of modern automobiles is a widespread use of mechatronic modules and systems. These modules are built as a symbiosis of electric, electronic and hydraulic components, united by means of the control system and intended to fulfill particular targeted functions.

In the article results of a comprehensive theoretical and experimental study aimed at creating a drive and a control system of a wheel module intended to be used with the steering and spring systems of an automobile and a mobile robot have been considered. Also the basic principles of the a complex of mechatronic drives of the wheel module (CMD WM) and technical requirements for the components of the complex as a mechatronic module of the system of active safety of the automobile and mobile robot have been formulated.

The operation of all the subsystems of the CMD WM of the all-wheel steering system with various types of the electro-hydraulic servo drive of wheel turning, and with the regulated wheel springing system and the onboard information and control system has been studied on the basis of the mathematical model.

Diagrams of all the components and of the CMD WM as a whole have been presented.

The automobile should be built as a complex of module-based mechatronic systems. An ideal automobile is a multi-functional mobile robot.

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INTRODUCTION

The automotive progress is dominated by qualitative changes in the structure and composition of the main power units, integration of electronic, electric, hydraulic pneumatic and mechanical elements, and an essential increase of the role of electronics and control systems, that is, a broad use of mechatronic modules in automobile designs. This process was triggered first of all by the fact that manufacturers of transport means have to stick to the toughest legislative requirements for active safety, as well as ecological norms, and standards on reliability, comfort and performance of their products. This fact brings closer by the essence the studies of the undercarriage of equipment transporters and mobile robots.

The Laboratory "Ground Wheeled Vehicles for Equipment Installation" of the Scientific and Manufacturing Center "Special Machine-Building" of the N. E. Bauman Moscow State Technical University has conducted a series of

fundamental and applied studies aimed to develop the theory and design of a mechatronic system of the wheel module of the equipment transporter and undercarriage of a mobile robot.

The object for application of the mechatronic system is a wheel module of the equipment transporter/mobile robot. A diagram of the wheel module is presented in [Figure 1](#). The general appearance of the equipment transporter/mobile robot is defined, first of all, by the type and design of the mover to be used as a converter of the energy of the power generating system into the traction force, which moves a mobile platform, in the process of interaction with the environment. The choice of the type and dimensions of the mover is a very complicated problem; and we have to agree with many technical compromises in order to solve it.

The complex of mechatronic wheel modules ([Figure 1](#)) is performing, when used in a vehicle/mobile robot, apart from the functions of the carrying system and mover of the

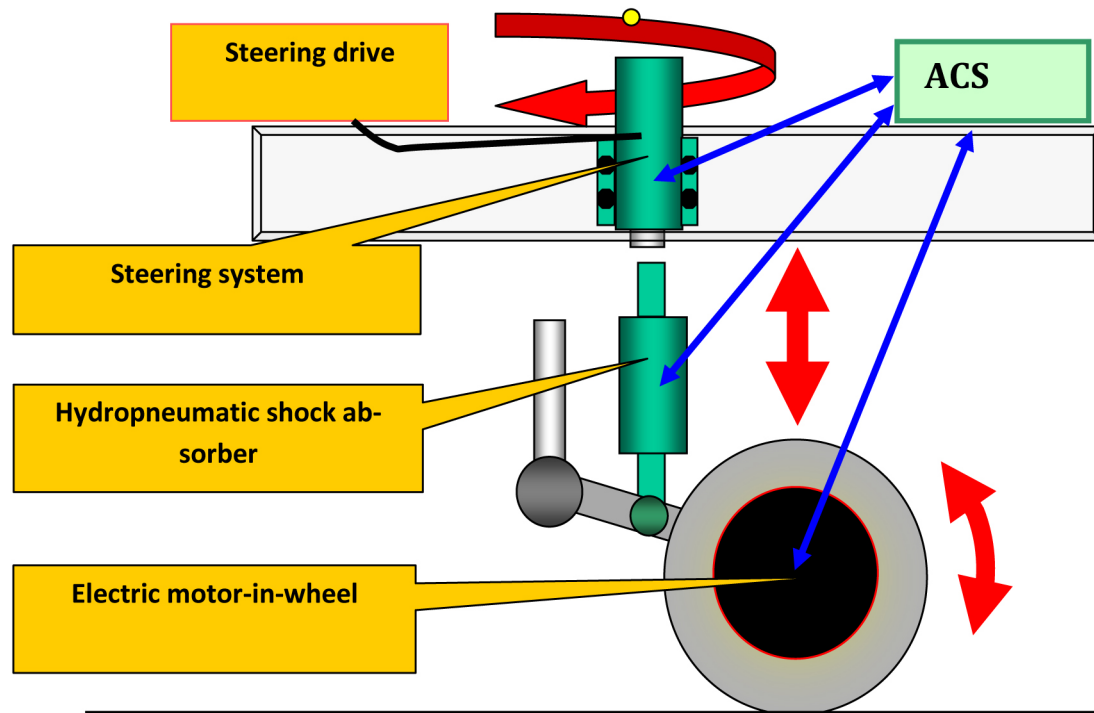


Figure 1. Functional diagram of the basic mechatronic wheel module: ACS - automatic (automated) control system

equipment transporter/mobile robot, a series of other important functions:

- control of wheel turning according to the predetermined law at nonlinear motion of the equipment transporter/mobile robot - the Four-Wheel Steering System (4WSS);
- control of the vibration level as a function of protection of the crew, equipment to be installed on the transporter and facilities of the mobile robot against vibrations - the Wheel Spring Controlled System (SCS);
- control of the horizontal stabilization of the vehicle body.

The importance of the above functions of the mechatronic wheel module assumes the following. Equipment transporters and mobile robots are often used in the severe road and climate conditions. Therefore, the use of the 4WSS, which significantly improves the vehicle maneuverability, is greatly broadening the usability of the equipment transporter/mobile robot. For example, the 4WSS allows making a turn of the equipment transporter/mobile robot in eight possible ways: relative to each of the axles and the plane-parallel (the so-called “crab-like”) motion (Figure 2). Moreover, the spring system should always ensure leveling of the vehicle body when moving off-road to exclude buckling or rollover. The vibration level control allows increasing the vehicle's off-road speed. It is known that different parameters of the spring system are required when traveling on and off roads. Therefore, the control system of the wheel module ensures adjustment of the wheel suspension, when the vehicle gets from the off-road terrain onto the road and vice versa.

It should be noted here that these 4WSS and SCS systems are parts of the active safety system of the vehicle/mobile robot.

These functions of the mechatronic wheel module are implemented by means of various types of the electrohydraulic drive. Such drives are easily integrated into remote and radio control systems of the vehicle.

The steering drive system, as a subsystem of the automatic motion control system of the equipment transporter/mobile robot, has the function of delivering the control action from the automatic control system to the controlled object - the wheels engaged in a nonlinear motion.

The 4WSS and SCS systems need an onboard computer. Their operation algorithms and software are usually companies' commercial secrets.

The idea of the 4WSS system is that the position of the turn pole is preset by the software in the corresponding functional form. The turn pole moves along the base depending on the steering angle (Figure 3). This ensures high motion stability at a slight trajectory curve and good controllability at maneuvering.

A doubtless positive feature of this system is that the driver operates a vehicle or equipment transporter in the usual and customary manner.

The use of the mechatronic wheel module with the electrohydraulic steering drive allows us to give up the bulky system of intermediary levers and pulling rods. Besides, the designs with an onboard computer are easily implementing any control algorithms and take a complete or partial control over the nonlinear motion of the vehicle.

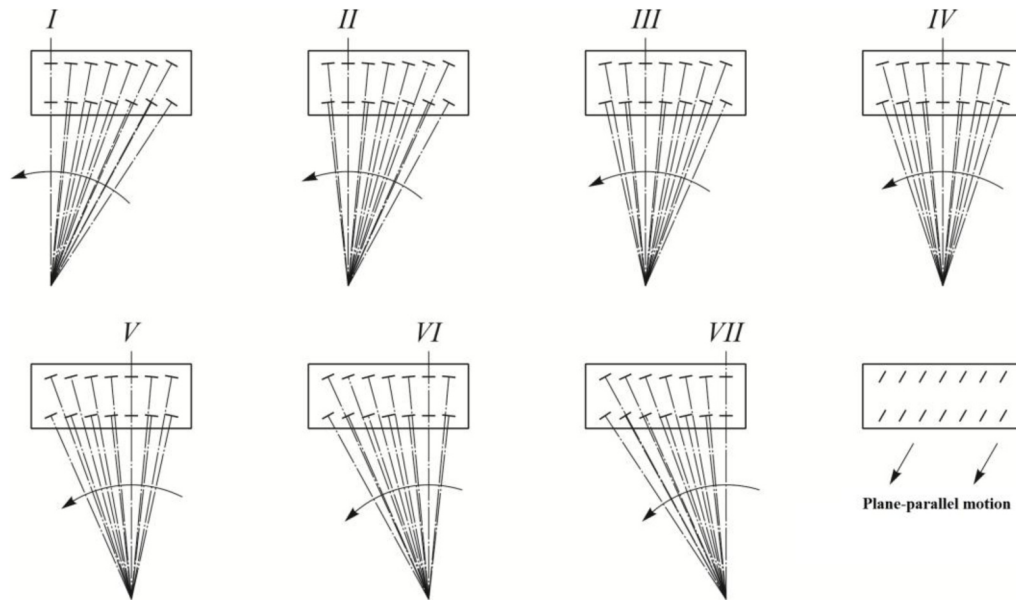


Figure 2. Kinematic diagrams of turning versions relative axes I-VII

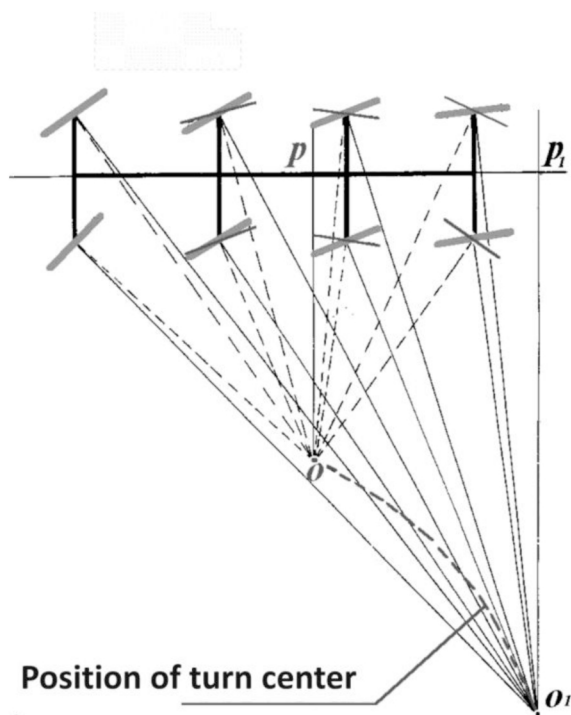


Figure 3. Diagram of the 4WSS system: O, O_1 - extreme positions of turn centre; P, P_1 - extreme positions of turn pole

With the aim to develop and justify the control law (algorithms) for the 4WSS and SCS systems for different motion conditions of the multifunctional equipment transporter/mobile robot, a complex mathematic model (CMM), describing the dynamics of the above systems with all their components has been designed (Figure 4). Individual

mathematic models (MMs) of the drive are integrated into the MMs of the springing and steering systems of the vehicle. The use of the electrohydraulic drive requires solution of a number of problems.

Thus, for correct implementation of the algorithms, it was requested to justify the parameters of the power and command devices of the automated control system (ACS) for the 4WSS and SCS systems, that is, of the hydraulic and electric parts of the electrohydraulic drive. So far, there are no methods for calculating such devices for the conditions, when a controlled wheel of the equipment transporter/mobile robot interacts with the support (rolling) surface. Besides, the design of the wheel module can make use of the electrohydraulic drive both with a centralized (Figure 5) and with an autonomous hydraulic system (Figure 6).

When studying the variants of the 4WSS and SCS systems for the wheels with the centralized hydraulic system, one should take into account the remoteness of the drives from power sources and an essential scatter in the values of the forces generated by the drive used in the equipment transporter. When the drive used for turning the wheels in the 4WSS is powered by an autonomous hydraulic system, one should take into account the need to realize different resistance moments to wheel turning, which are caused by redistribution of forces among the wheels and by the properties of the support surface.

Besides, in case of an autonomous hydraulic system, researchers face a choice among the throttle (Figure 6a) and volumetric (Figure 6b) control.

Let us now consider possible approaches to solution of the above problems, when designing the electrohydraulic drive. In case the boundary conditions are also expressed by differential equations, the solution of such a system may be