Using strain gages to assess the bearing properties of underlying surface with a robot crawler

K Mashkov¹ and T Pozdnyakov¹,²
¹Bauman Moscow State Technical University
²E-mail: t.pozdnyakov@bmstu.ru

Abstract. The advent of military robotic systems has raised requirements for control systems, especially independent motion control, in particular, lateral possibility and flotation when moving in partially defined or undefined environment and in the presence of external perturbations. This paper proposes approaches to determine bearing reactions under the dynamic interaction of RV running gear with the bearing surface. It demonstrates a set of gages built into the tracked running gear allowing to evaluate the underlying surface properties. It proposes a computer-aided engineering system based on the finite element method to identify the most efficient locations to install strain gages.

Keywords. Robotic systems, flotation, finite element method, strain gage

1. Introduction

Advancement of robotic vehicles (RV) is directly related to the development of the necessary artificial intelligence technologies [1–3].

In terms of control type, RV systems can be divided into three groups:

- remotely controlled
- remotely controlled with autonomous motion elements
- autonomous.

As the necessary artificial intelligence and autonomous robotics technologies are developed, remote controlled robot vehicles become more and more capable gradually moving away from operator control to partial autonomy in performing the overall task.

The third group of vehicles is of particular interest for science. This is the class of robotic vehicles capable of unmanned motion and performing various kinds of tasks in partially defined or undefined environment and in the presence of external perturbations.

The automatic motion control system (AMCS) shall ensure lateral passability and flotation of RV, including:

- integrated processing of information from onboard sensors, machine vision and navigation systems with reference to the digital terrain map
- automatic real-time trajectory (path) planning (correction)
- path testing including RV obstacle avoidance and control automation at all stages of movement.

The control system shall ensure lateral passability and flotation of RV.

The problems of lateral passability of autonomous robots are mainly solved today based on machine vision systems [4–8]. However, the full-scale problem of RV autonomous control requires the design and implementation of a flotation system.
One way to determine the flotation is mathematical simulation of the robotic vehicle behaviour in specific soil conditions. The main task of this subsystem is the dynamic simulation of robot movement based on measured inputs (angular velocity and torque of traction wheels) during cross-country movement of the robot, as well as specific soil-propulsor interaction. To do this, the subsystem shall solve the inverse problem of determining road soil conditions and adjusting the control action on actuators based on dynamic effects of the subgrade on the running gear.

Mathematical modelling of RV as a control object is quite challenging. Firstly, RV is a complex mechanical system consisting of a large number of mechanically coupled subsystems (body and attachments, wheeled or tracked running gear with a transmission, cushioning subsystem, etc.). Secondly, RV often moves on rough terrain replete with a variety of obstacles: downgrade and upgrade, uphill slopes and ravines; in these conditions, the mathematical model must simulate RV movement in 3D. Thirdly, RV movement involves slipping and skidding associated with soil deformation.

Information on subgrade soil and nature of soil-propulsor interaction is obtained using methods based on different physical tactile, acoustic principles on the basis of a complex machine vision system according to stresses arising in the propulsor and running gear as a whole and other [9–20].

Previously, the most common methods were undertaken using strain-gage tracks, but went nowhere due to the imperfection of technologies at that time. Today the development of microprocessor technology and AMCS requirements make the use of strain-gage tracks feasible [21].

It should be noted that the problem at hand is easily solved at the design stage for light tracked RVs equipped with radiotransparent solid rubber or polyurethane crawler tracks (Fig. 1 and 2), when the strain gage is baked into the track body.

Installing strain gages on medium- and heavy-weight vehicles is more challenging. It is particularly difficult to install gages in the track pin.

Some track pin designs enable the installation of strain gages, in particular, when it has a hollow center as in Fig. 3.

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Fig. 1. RV track link weighing 200 kg with removable grouser
Fig. 2. RV track link weighing 700 kg with a metal liner

Fig. 3. Track pin with a hollow center

2. Model Description
When tracked RV is moving, the track pin experiences tensile loads (Fig. 4). These loads are defined as static tension of the track envelope and dynamic effects from RV movement. The maximum efficiency of gages can be achieved by installing them in regions of the highest strain.

Fig. 4. Track pin load diagram
This paper proposes to identify such regions using mathematical simulation based on the finite element method (FEM) [22–23]. FEM is currently widely used for research and design. The advantages of FEM are minimum costs and time to obtain results of the most stressed regions compared to a series of experiments, but FEM-based mathematical simulation can not replace experimental testing. This is because the mathematical model can be highly simplified as compared to the real system, and simulation results will not fully reflect the behaviour of a real object. Experimental tests confirm the correctness of the chosen mathematical model.

Fig. 5 and 6 show a model of RV track pin.

3. Simulation Results
It is convenient to use equivalent stress to identify the most stressed regions. Von Mises equivalent stress is conventionally used for plastic materials:

\[
\sigma_{\text{equiv}} = \frac{1}{\sqrt{2}} \sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{yz} + \tau_{zx} + \tau_{xy})^2}
\]
Fig. 7–9 show the distribution of displacement and equivalent stress in the pin during its operation as part of the tracked running gear.

**Fig. 7.** Displacement distribution, mm

**Fig. 8.** Equivalent stress distribution, MPa
4. Results and Discussion
The analysis of simulated results allows us to conclude that the greatest displacement occurs in the pin interface with the track clamp.

It is most expedient to use an annular strain gage to assess pin loads. Its schematic design is shown in Fig. 10.

The annular strain gage provides data on the loading of RV track link.

Therefore, modern computer-aided engineering systems based on the finite element method allow to identify the most efficient locations to install gages. Computer-aided engineering systems enable us to select and design a gage, which in turn will allow necessary data to be obtained for AMCS.
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