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Stress and Strain Analysis in Critical Joints of the Bearing Parts of the Mobile Platform Using Tensometry

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Abstract At present, there has been a rapid advancement in the use of new materials and modern technologies in the design and technical improvement of robotic systems. Methods of numerical modeling are most commonly used in the design and development of load-bearing parts of mechanisms. When designing complicated mechanical systems such as robotic systems, it is often difficult to correctly define boundary conditions that correspond to the actual operational state using the results obtained through numerical modeling. The paper presents methods of verification of the results obtained by numerical modeling in the selected load-bearing component of a six-leg robot from experimental measurement using tensometry with the aim to take into account the strength and stiffness parameters of the load-bearing part in order not to jeopardize safe and reliable operation of the mobile robotic platform.

Keywords: *robotic systems, numerical modeling, stress analysis, tensometry*

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1. Introduction

Caterpillar and wheel robots belong to the group of most commonly used mobile service robots used for a wide variety of applications both inside and outside, Fig.1. There are many mobile wheel systems with more or less complicated structures. Wheel chassis as a locomotive mechanism of mobile service robots differ from each other mainly in the number of wheels and control method. When designing the chassis of a mobile service robot it is important to consider its operation mode and the environment when it will be deployed [1]. The drive modules must be able to provide the required rotation or advance motion. The modular structure of robots enables their fast and effective adjustment to the requirements imposed on them.

At present, mobile robotic systems are being actively developed. The wide range of service activities requires using various principles for the mobility of service robots [3]. The most widely used application is the principle of a wheel chassis. In terms of theory and technical design, wheel chassis are the most developed and most widely used in the service robotics.

Complex mobile robotic systems are suitable to use in tough conditions such as:
- rescue works carried out in the event of natural disasters (works in debris, search and rescue of survivors),
- early emergency handling in case of chemical, nuclear and other industrial accidents (polluted environment, fire, etc.),
- checking and intervention in the endangered areas.

Figure 1. Types of driving mechanisms of mobile robotic systems [2]

Figure 2. Application of wheel robotic systems [2]

The primary importance in the field of service robotics lies in following and adapting to the most current trends, namely in:

- integration of drive modules with distributed intelligence,
- increasing robot mobility by application of biokinetic structures,
- autonomy and cognitivity of robots, their ability to cooperate with humans as their assistants,
- multiagent application of robots performing a joint task with the ability to change the strategy depending on the outdoor conditions.

The paper describes application of numerical and experimental methods of mechanics in the design of a mobile service robot of middle category (Figure 3) which consists of two basic parts [4]:

1. a mobile platform that enables autonomous motion in the rough terrain and ruins with payload capacity for the body weight 400 kg, max. speed 3 or 5m/s and climbing ability 45°,
2. a robotic arm with 6 degrees of freedom and nominal load capacity 200 kg.

Figure 3. 3D model of the complex modular robotic system [4]

Functional (physical) models of the above-mentioned modules were optimized by simulation computer models and tested in actual conditions using experimental methods of mechanics.

2. Description of the Problem

Robotic systems can be considered as complex mechanical systems not only in terms of kinematics but also from the point of view of the analysis of various stress and strain states due to a variety of operational loading. A six-leg mobile robot was chosen for the stress and strain analysis. Multiple bearing elements were considered by numerical modeling using finite element method when designing and optimizing the bearing structure of the mobile platform. Main bearing parts of the mobile platform were designed in such a way as to ensure that their loading did not exceed the computational strength of the given material and that the deformations that occurred satisfied the required function.

To verify the results obtained using experimental methods of mechanics, a robot leg was chosen. The finite elements method was used to identify critical areas for the application of strain-gages. The robot leg was loaded at the place of the suspension of the wheel. Various combinations of the positions of individual robot legs were considered in the calculations. Figure 4 shows the above-mentioned model of the outstretched robot leg with boundary conditions (Variant A).

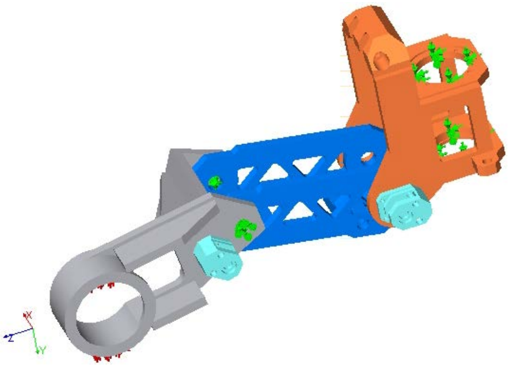

Figure 4. Computational model of the outstretched leg (variant A)

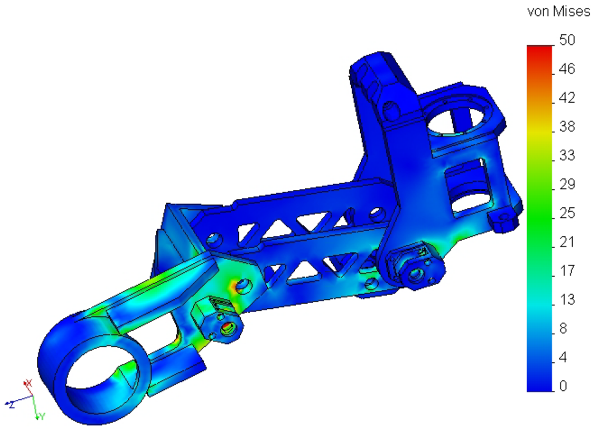

Figure 5. Field of equivalent stresses, variant A

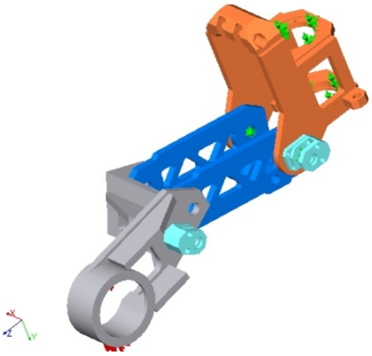

Figure 6. Computational model of the outstretched leg (variant B)

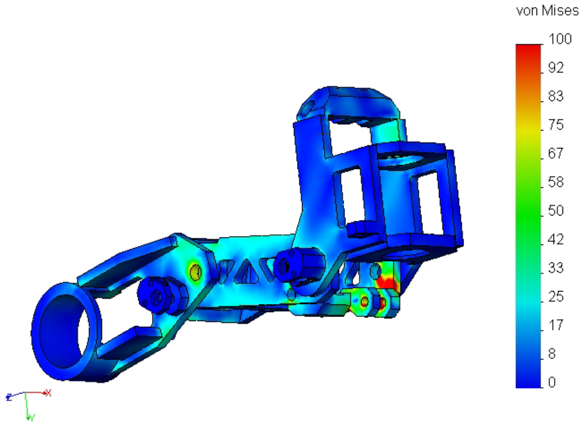

Figure 7. Field of equivalent stresses, variant B

Figure 5 shows the field of equivalent stresses in the robot leg according to von Mises theory of strength, variant A.

Figure 6 shows the model of the robot outstretched leg with boundary conditions (Variant B).

Figure 7 shows the field of equivalent stresses in the model of the robot leg according to von Mises theory of strength, variant B.

Based on the analysis of the results obtained by numerical modeling, the areas for the subsequent verification using experimental methods of mechanics were chosen.

3. Strain-gage Measurement on the Leg of the Mobile Robot

Fig. 8 gives a general view of the mobile robotic system. For the purpose of experimental measurement, a leg of the mobile robot (Figure 8) was chosen, where strain-gages were applied. Type of strain-gage XY91-10/120, factor k=2,03, connected to the half-bridge [5]. Measuring grids of the strain-gage were positioned in the direction of the axis of the leaned leg. Compensation sensors were directed perpendicularly to the axis of the active sensors. Two-component adhesive X60 and covering agent SG250 were used for the application of straingages. Time records of the relative deformations in selected areas were recorded by SPIDER8 measurement unit with Catman software.

Figure 9 shows the process of the application of strain-gage.

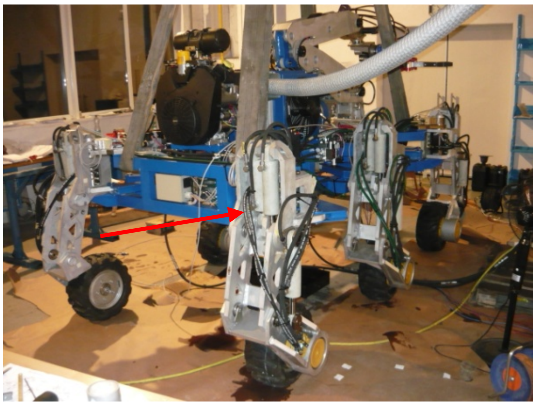

Figure 8. General view of the mobile robot

Figure 9. Application of strain gage

Figure 10 shows strain-gages applied in places 1 to 5 of the body of the leg of a mobile robot.

Figure 10. Applied strain-gages in places 1 to 5

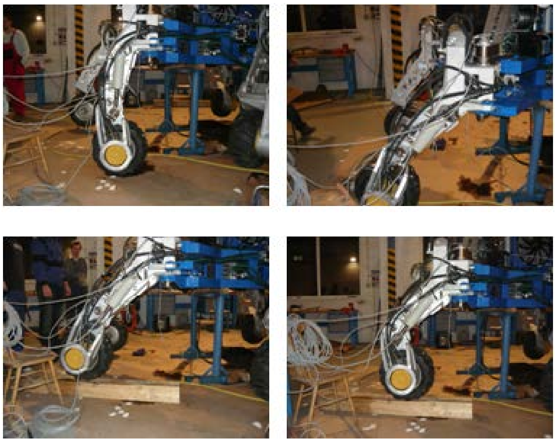

Figure 11. Selected positions of the robot leg during experimental measurement

Table 1. Description of the phases of experimental measurement

Phase	Description of the operational mode
I	Unloaded state 0 – 50 s. Stretched leg 50 - 60 s. Lowering of the wheel to the ground (leant against the ground) 60 - 95 s.
II	126 – 131 s. lifting of the stretched leg. Within about 140 s. insertion of the timber, leg handling.
III	162 – 172 s. process of lowering the wheel in the stretched position up to its leaning against the timber. 172 – 235 s. jumps caused by placing the leg with the wheel against the timber.
IV	Within 240 s. lifting of the wheel and changing the position of the last component of the leg in the pin (tipping). Within 260 s. completing the change of the position adjustment.
V	268 s. lowering of the wheel, 279 s. leaning against the timber.
VI	401 s. adjustment of the last component of the wheel as a result of the tipping of the whole mobile robot due to straightening the leg.
VII	446 s. adjustment of the last element of the wheel – loss of pressure contact of the wheel with the timber 490 s. returning of the leg to the initial position.

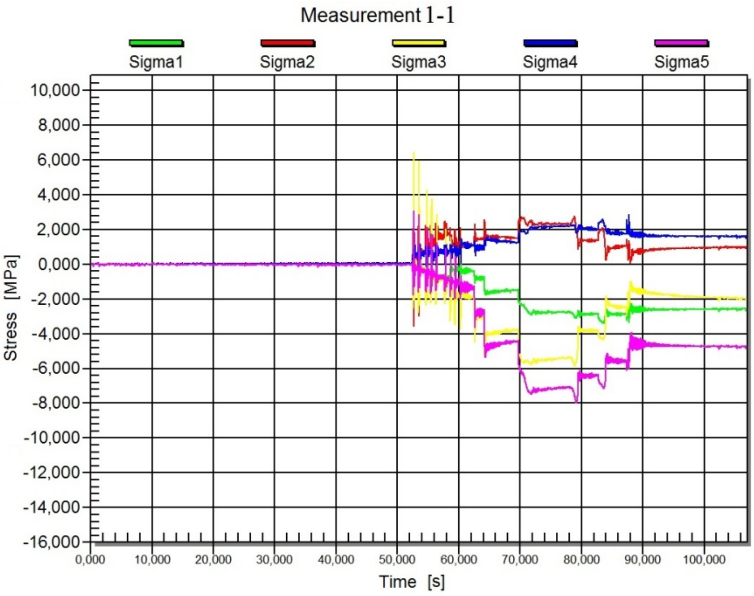

Figure 12. Time courses of stress in places of measurement 1 - 5, phase I

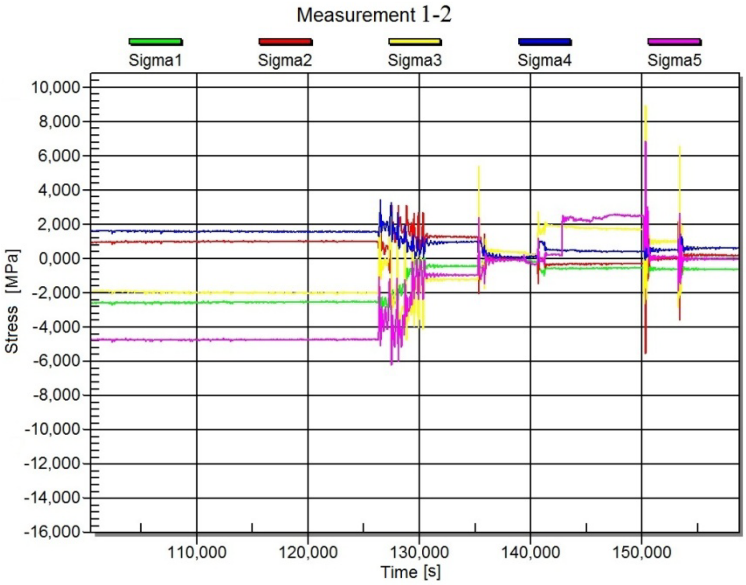

Figure 13. Time courses of stress in places of measurement 1 - 5, phase II

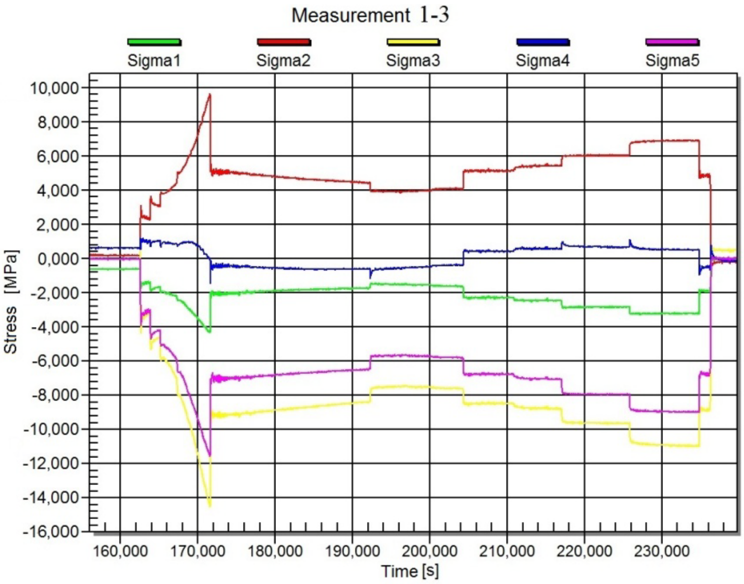

Figure 14. Time courses of stress in places of measurement 1 - 5, phase III

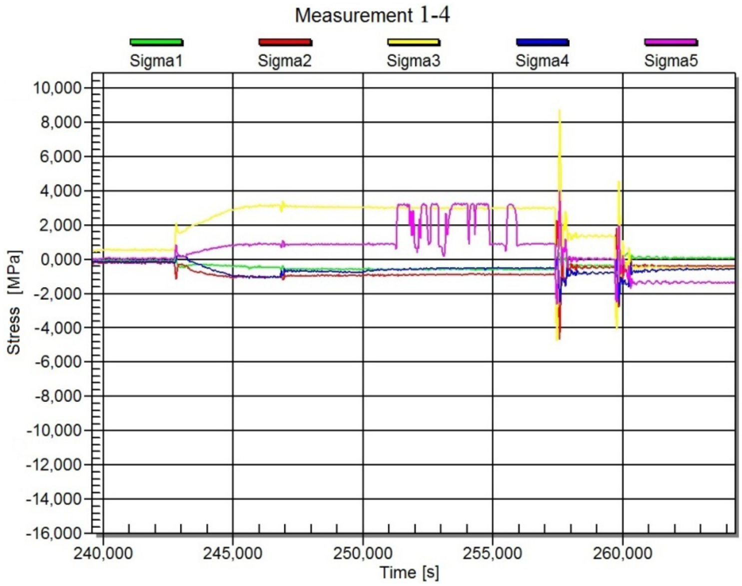

Figure 15. Time courses of stress in places of measurement 1 - 5, phase IV

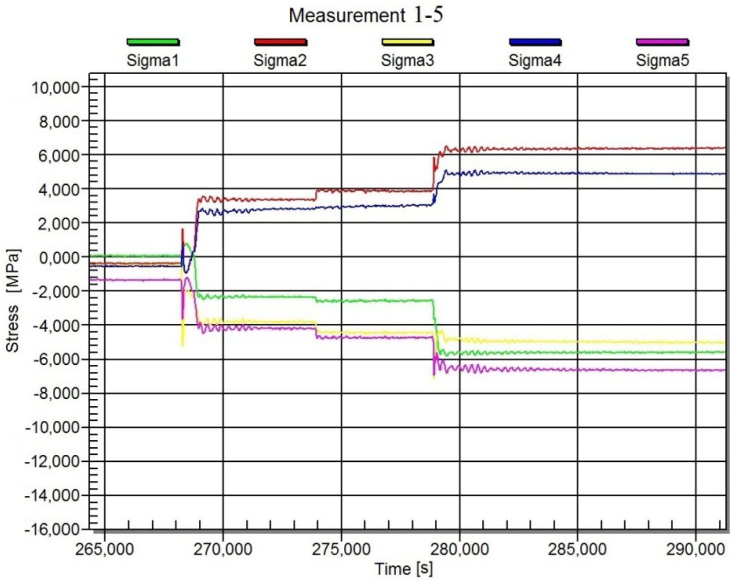

Figure 16. Time courses of stress in places of measurement 1 - 5, phase V

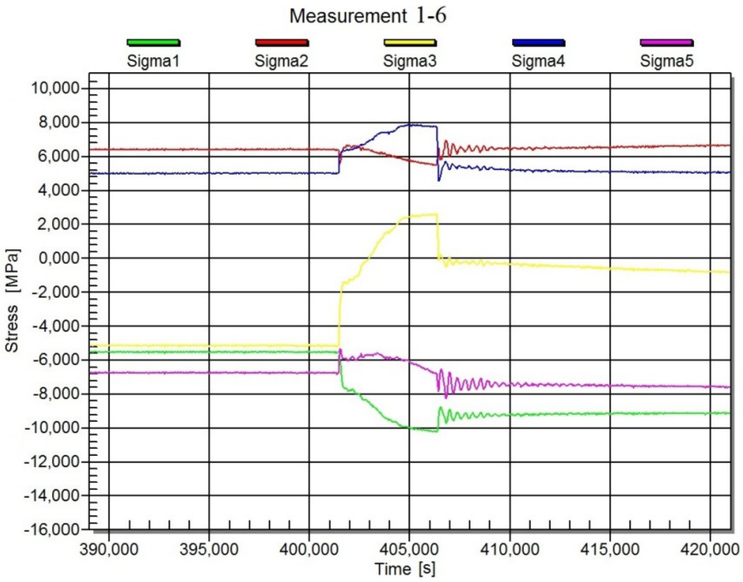

Figure 17. Time courses of stress in places of measurement 1 - 5, phase VI

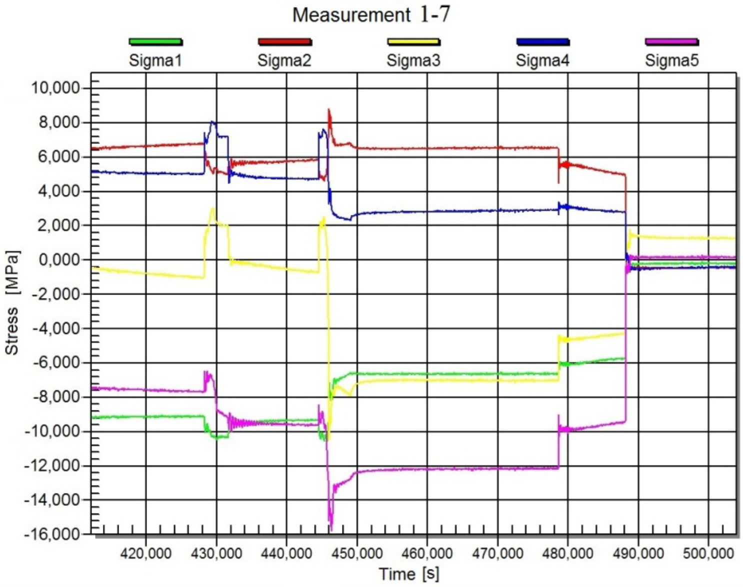

Figure 18. Time courses of stress in places of measurement 1 - 5, phase VII

The next part gives the results of the selected measurements of relative deformations and stress in the individual measured places at the selected modes of the leg loading. Figure 11 shows different positions of the robot leg at which the experimental measurements were performed. Figure 12 – Figure 18 show the stresses in places where the strain-gages were applied at the defined operational modes according to Table 1. The presented strain-gage measurement took about 490 s.

4. Conclusions

In spite of the fact that nowadays great emphasis is placed on the optimization of the shape and geometry of the bearing parts of machinery and equipment in order to reduce their weight, it is necessary to state that when designing bearing parts of the mobile robotic systems of manipulators it is essential to pay close attention to the rigidity parameters of the used components. It is very important in terms of exact positioning of the end elements of the mobile robotic systems designated for application in tough conditions of rescue works, natural disasters, fires, decontamination of surfaces from toxic materials, etc., where accuracy is top priority.

The paper presents the method of verification of the results obtained using numerical modeling by experimental measuring performed in the defined areas on the robot leg of the mobile platform in different positions at the operational loading. Based on the stress values obtained by experimental measuring it can be concluded that the proposed shape, geometry and material of the robot leg in terms of hardness a strength are sufficient and the mobile platform can be safely operate without restrictions.

Acknowledgements

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