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ANALYSIS OF THE LOADS ON POWER TRANSMISSION SYSTEM OF UNDERCARRIAGES WITH ELASTOMER TRACKS

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Abstract

The study is devoted to an analysis of the working conditions of the running gear elements with elastomer tracks in the typical applications of an industrial vehicle. The loads of the undercarriages elements for the selected running gear with elastomer tracks were determined on the basis of this analysis. Particular attention was paid to the operation of the inner track lugs (during the drive transmission and track guiding), and the elastomer lining of the driving sprocket. Numerical computations were conducted by means of the finite element method using nonlinear static. The elastomers used in running gears, mainly the rubber with various mechanical properties (for instance hardness) were modelled as incompressible hyperelastic materials using the two-parameter Mooney-Rivlin model The computations took into account contact effects and friction in the areas of the mating elements contact. The results of the numerical analyses demonstrate the possibilities of increasing the loads transmitted by the analyzed elements of the running gear. The local character of the loads in the drive transmission system using the positive power transmission is noteworthy. The results of the computations may be used for the optimal dimensioning of the elastomer elements of the drive transmission system between the driving sprocket and the elastomer track.

Keywords: *elastomer track, running gear, FEM numerical computation, track vehicle operation*

1. Introduction

Undercarriages with elastomer tracks, increasingly more frequent in selected groups of industrial vehicles, make use of the significant advantages offered by the new possibilities resulting from the application of elastomer tracks. They make it possible: to achieve high traction efficiency at low pressure on the ground, to operate the track vehicle on public roads without the fear of damaging them, to move at high velocities, to achieve a significantly smaller mass in comparison with the conventional metal tracks and also to carry out drive transmission between the driving sprocket and the track in various ways. Two main methods of power transmission are used: the friction and the positive drive transmission (Fig. 1), which feature significantly different properties [4].

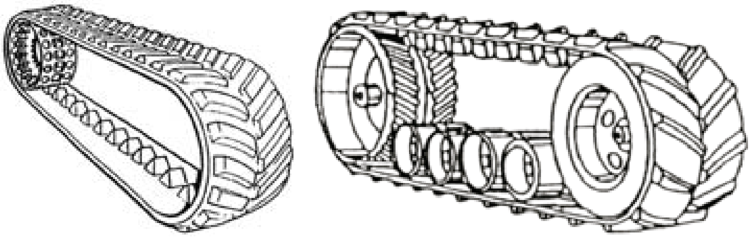

Fig. 1. Examples of the positive (Track Marshall) and friction (Caterpillar) drive transmission [4]

The innovative hybrid drive (Fig. 2) [1], which combines the positive features of both methods of drive transmission mentioned previously, constitutes an attractive alternative, especially with vehicles which are supposed to move on various surfaces in changeable conditions. It makes it possible to use the drive transmission system between the driving sprocket and the elastomer track optimally, with the guarantee of the power transmission in all conditions while retaining quite high durability of the elastomer track. The hybrid drive operates in the following way: the main system which is permanently used is the friction power transmission system, whereas the system of the positive power transmission is additionally activated in emergency situations (for instance when there is slipping between the driving sprocket and the elastomer track) or when it is necessary to use brakes of the vehicle (for instance during a stop or on a slope).

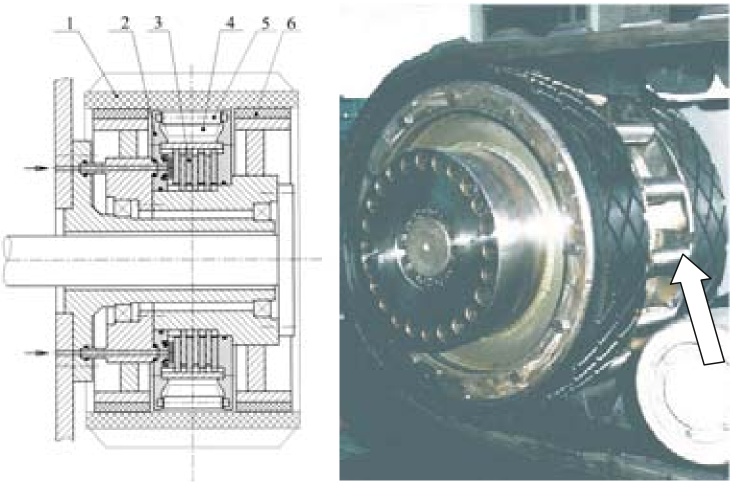

Fig. 2. Hybrid drive [6] (1– elastomer track, 2–idler, 3–clutch, 4-inner track lug, 5-pin/roller, 6-elastic lining)

Undercarriages with elastomer tracks have been improved since the beginning of the twentieth century. However, their rapid development has been witnessed over the last two decades. Given the structural similarity to the conventional systems (with steel tracks) it might have seemed that designing undercarriages with elastomer tracks should cause no major problems. However, it turns out that the specificity of the drive transmission, different properties of elastomer materials, especially of the track, require a more detailed analysis of the loads transmitted by the running gear.

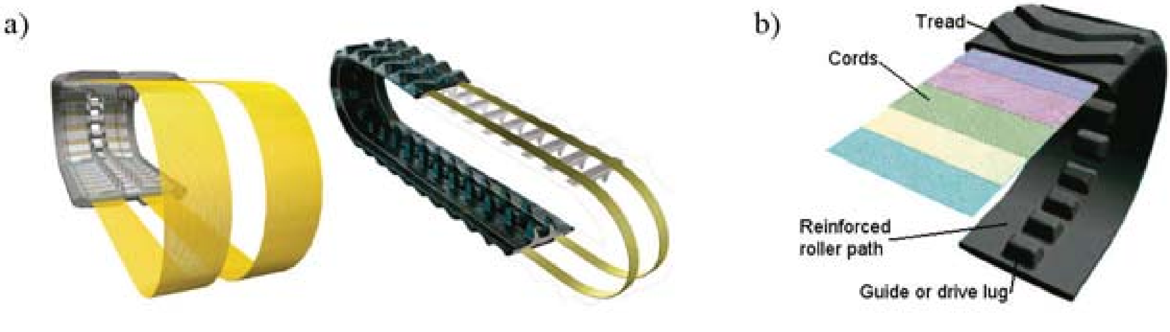

Fig. 3. Elastomer tracks for the positive (a) and friction (b) drive transmission [7]

Elastomer tracks used in industrial vehicles have different outer track shapes (an equivalent of the tire tread) [7] and different guide lugs and drive lugs [7]. The internal structure depends on the power transmission method: in case of the positive power transmission tracks with an internal chain are often used, in which the drive from the driving sprocket is transmitted to steel elements (Fig. 3a). An alternative solution is tracks in the form of a rubber cable with a tread on the outer surface typical of vehicles moving on soft ground, the internal surface of the track has guide lugs and a reinforced rolling surface for track rollers. The track is reinforced with layers of fabric or steel cords (Fig. 3b).

2. Loads of selected elements of the undercarriages with the elastomer track

a) elastomer track

The elastomer track belt is subject to various loads due to the complex character of its operation, with the most significant ones as follows:

- track tensile force - the value of this force is very significant for the distribution of the unit pressures under the track (concerns soft grounds) [4], the value of the internal resistance generated by the mating elements of the running gear and the durability of the elastomer track;
- track bending - it occurs when moving the elastomer cable over the wheels and the rollers of the running gear - the impact of this load depends on the track tension, the properties of the materials and the thickness of the track, especially regarding the wheel diameters over which the track is moved;

b) elastomer inner track lugs

- inner lug loads during track guiding

During the operation, in the changing working conditions, the inner lugs of the elastomer track are subject to various loads resulting from the mating of their side surfaces with the wheel surfaces: the driving sprocket and tension wheel and the track and carrier rollers. As a result of the movement on a slope, on a curvilinear course or asymmetrical road irregularities the track is subject to forces which could, had it not been for the guide lugs, lead to the slipping of the track from the elements of the running gear. It should be noted though that the side force is not entirely transmitted by the guide lugs. Depending on the lateral stiffness of the track some portion of the side force is transmitted due to the frictional contact of the track and the wheels of the running gear. In case of the driving sprocket and the tension wheel this force results from the pressures of the track on those wheels (the track tension effect), whereas in the case of track rollers the force affecting the internal surface of the track results from the radial loads transmitted by the rollers. The friction forces transmitted by the wheels and the track rollers cause that the effective load of the guide lugs with side forces is not high, especially when one takes into account: the large number of track guide lugs (the typical pitch is 50÷100 mm [7]) and the frequently used high track tension forces (for instance 142-222 kN in Challenger MT700B and MT800B Caterpillar tractors [7]).

- inner lug loads during drive transmission

Due to the vast range of structural solutions applied in the positive power transmission a choice was made to analyze the loads of track guide lugs which accompany the drive transmission in the aforementioned prototypical structural solution of the hybrid drive (Fig. 2). This solution applies bolts which are in permanent cooperation with the inner track lugs, but until the clutch is activated they only transmit the loads resulting from the slight resistance in the sprocket bearings. When the clutch is activated the drive between the driving sprocket and the track is transmitted both by the positive coupling and the frictional contact. The results of the experimental studies [2] demonstrate that even in the extreme working conditions of the drive, at a significant decrease of the frictional contact coefficient (below 0.05¸ 0.1), the friction transmission method may transmit some of the required driving torque - approx. 15%. This value may be improved (up to approx. 25%) if the running gear is equipped with a tension system that provides the possibility to control the tension force - increasing the tension of the track should be limited due to the permissible loads of the running gear elements and the durability of the track.

When it comes to the positive power transmission the distribution of the loads throughout the entire arc of wrap of the driving sprocket is significant. There are 8 guide lugs (Fig. 4) on the arc of wrap in the discussed solution (Fig. 2). The most favourable, uniform load distribution of bolts throughout the entire arc of wrap is rather theoretical. The results of studies from the previous literature regarding the loads of the driving sprocket teeth in cooperation with the steel track [8] demonstrate that there is significant non-uniformity of the sprocket teeth loads on the arc of contact: the first tooth transmits approximately 80% of loads. Greater flexibility of the rubber elements of the running gear with the elastomer track (the friction lining of the driving sprocket, the track, the lug without additional reinforcing elements) makes it possible to assume a more favourable distribution of the inner track lug loads.

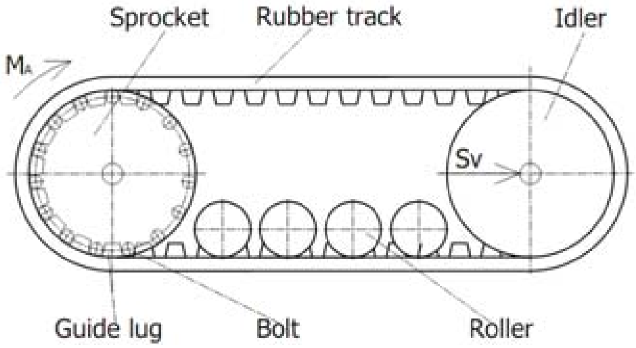

Fig. 4. The diagram of the driving system (M_A- driving torque, S_V – tension force)

c) driving sprocket lining

The friction linings applied in the friction drive transmission systems aim at increasing the generated friction coefficient between the driving sprocket and the internal surface of the track. The additional purpose of the lining is to eliminate impurities from the cooperating surfaces of the friction lining and the track (Fig. 5). This is achieved by forming grooves on the surface of the lining, whose shape and the size should be adequate to the type of impurities that can occur during operation. The loads of the driving sprocket lining result from the method of the drive transmission. The condition for generating the frictional contact between the driving sprocket and the elastomer track is the track pre-tension which results in unit pressures. Given the driving torque transmitted by the frictional contact and the resulting difference between the force in the active and passive cable there are also tangential loads in the lining whose distribution depends on the driving direction and the value of the transmitted torque.

Fig. 5. Elements of the drive transmission system with impurities [2]

4. Numerical computations

Computations regarding elastomer materials (sprocket lining and inner track lug) assumed non-linear, two-parameter Mooney-Rivlin model and the model parameters were determined on the basis of the known rubber hardness [3].

a) elastomer inner track lugs

In order to conduct a numerical analysis of the inner track lugs a two-dimensional computation model (Fig. 6) was developed. One pair of cooperating elements was isolated: a rubber inner track lug and a steel bolt of the sprocket.

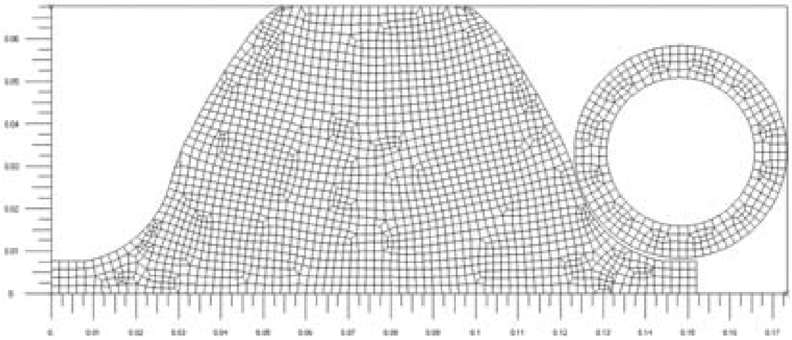

Fig. 6. Discrete model of the elements of the analyzed system: rubber inner track lug and steel bolt of the sprocket

The following assumptions resulting from the aforementioned considerations and the technical data of the laboratory stand [6] were adopted in the computations:

- it was assumed that the positive coupling transmits 2/3 of the required driving torque,
- the possible impact of the inner track lug loads on the frictional contact between the elastomer track and the driving sprocket was disregarded,
- the impact of the track tension was disregarded,
- non-uniform distribution of the inner lug loads on the arc of wrap was assumed given that the 'first' most loaded inner lug transmits 50% of the loads,
- phenomena accompanying the activation and deactivation of the clutch of the positive transmission were not analyzed in the model,
- the inner lug load was modelled using the frictionless contact between the bolt and the inner track lug.

Figures 7 and 8 present example results of numerical computations.

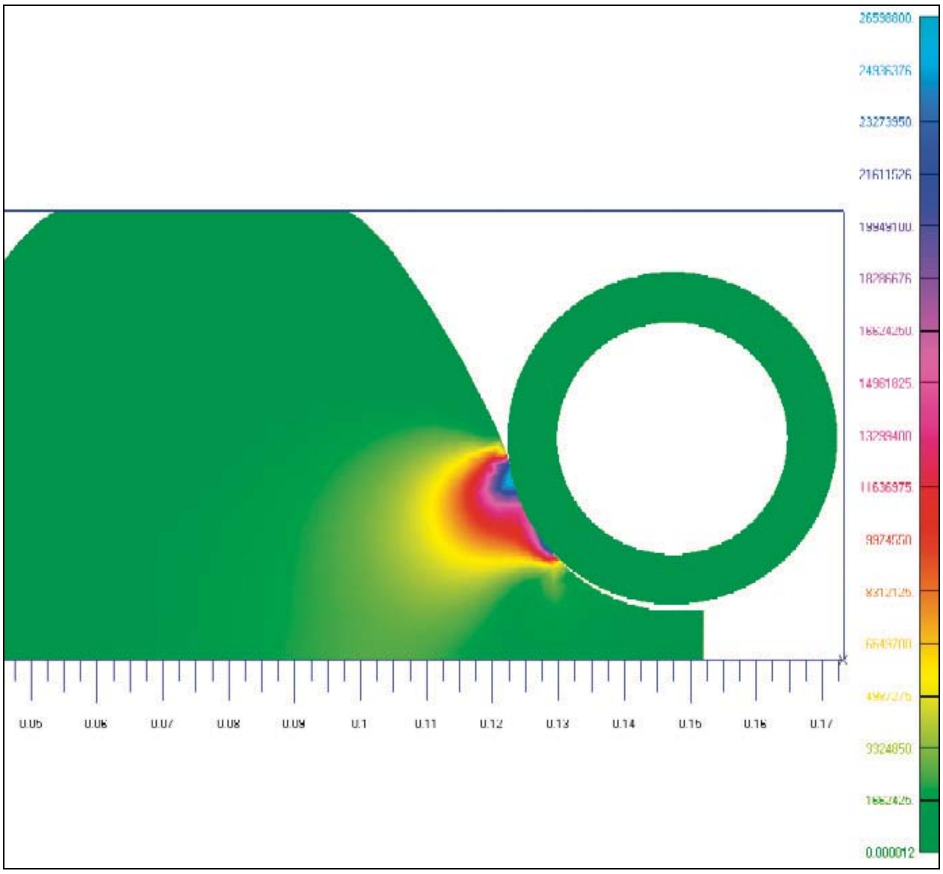

Fig. 7. Stress distribution in the inner lug of the elastomer track (stresses in [Pa])

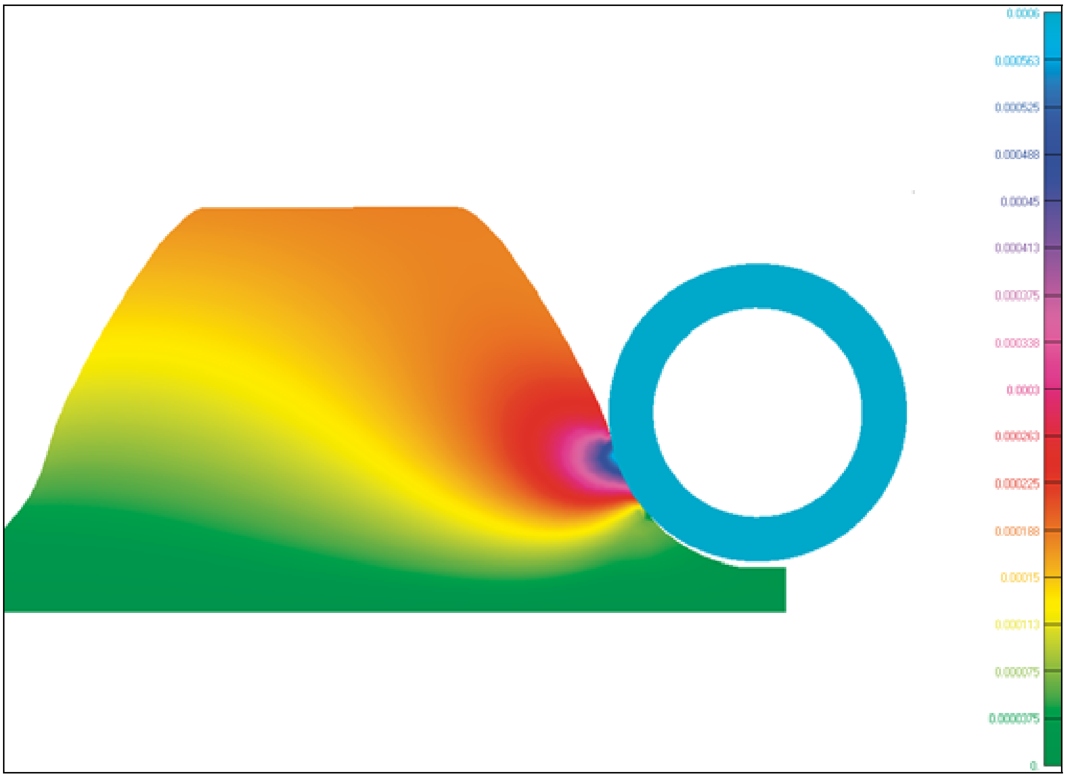

Fig. 8. Deformation distribution of the inner lug of the elastomer track (displacements in [m])

a) driving sprocket lining

In order to conduct a numerical analysis of the friction lining working conditions a two-dimensional computation model (Fig. 9) was developed in which an arc sector of the cooperating element (the rubber lining of the driving sprocket and the elastomer track belt) was isolated.

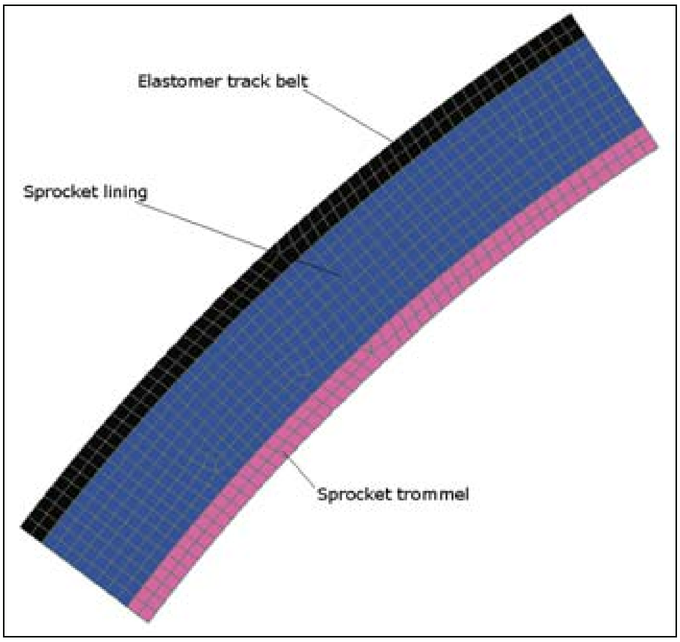

Fig. 9. Discrete model of the elements of the analyzed system: driving sprocket lining and the elastomer track belt

The following was assumed in the computations:

- the driving torque is transmitted exclusively by the contact of the track with the driving sprocket lining,

- only the internal surface of the track with the steel warp cords participates in the transmission of the drive,
- the thickness of the lining is constant,
- the friction coefficient between the driving sprocket lining and the internal surface of the track is constant and independent of unit pressures.

Figures 10 and 11 present example results of numerical computations.

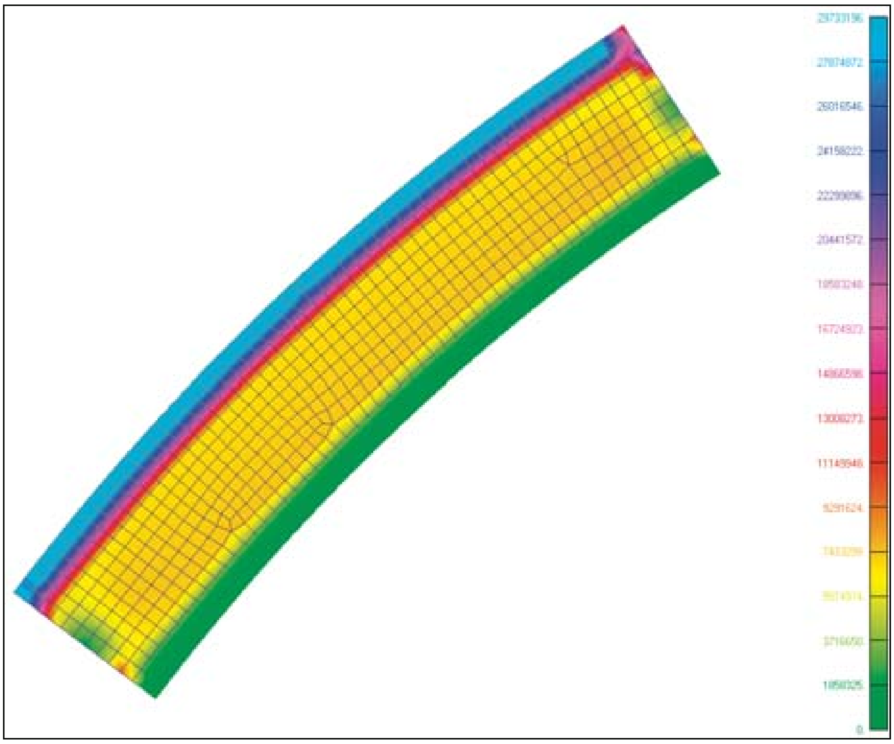

Fig. 10. Stress distribution in the elastomer driving sprocket lining (stresses in [Pa])

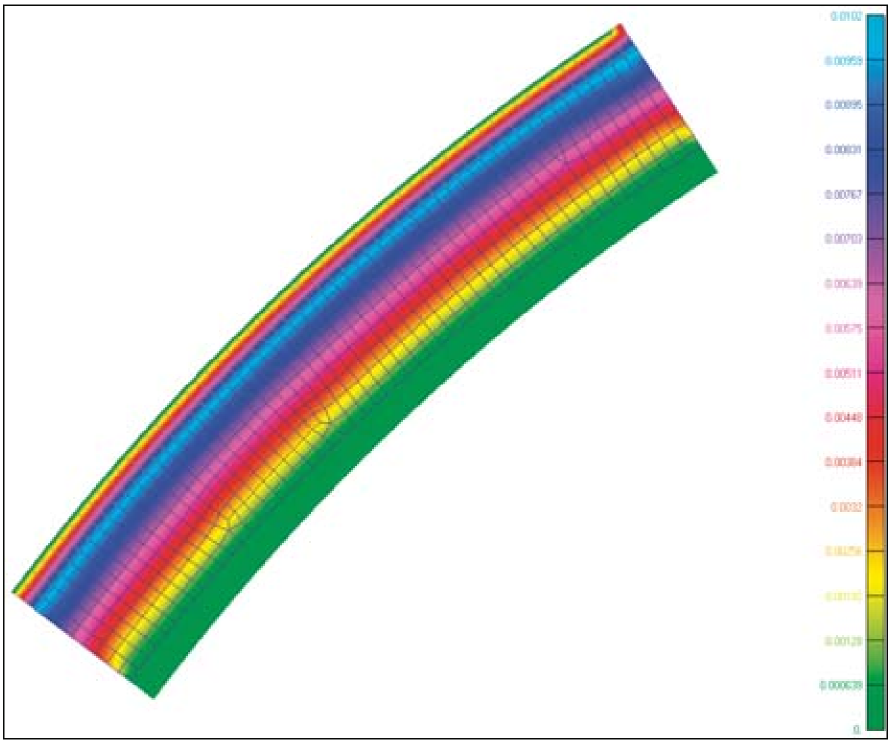

Fig. 11. Elastomer lining deformations (displacements in [mm])

5. Conclusions

The results demonstrate that the deformations of the inner track lug for the assumed computational model of the track are slight and they are local - the displacements of the lug as a ‘whole’ are negligible. Stresses in the inner track lug do not exceed the permissible values. The results demonstrate the possibility of increasing the load of the power transmission system beyond the rated values which are provided in the technical documentation of the investigated running gear.

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