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ENERGY EFFICIENCY OF RUBBER TRACKED CHASSIS

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Abstract

Nowadays, increasing number of machines and off-road vehicles are equipped with elastomeric, mainly rubber, tracked chassis. Rubber tracks and belts combine the most important advantages of both: pneumatic tires and conventional tracks made from metal links. In spite of significant benefits, rubber tracked chassis is a novel and uncommon design solution, as the application of rubber tracks and belts still brings up many severe problems. Consequently, an urgent need to overcome these problems exists.

In The Division of Off-Road Machine and Vehicle Engineering (DORMVE) an intensive research, pertaining to rubber-tracked chassis has been conducted for many years. In the very beginnings, the investigation was carried on in cooperation with German companies INTERTRACTOR, IAMT and IBAF. As a result, numerous original and innovative design solutions, which became a subject of European, American and Japanese patents, were developed. However, some issues have not yet been resolved.

Present research of DORMVE is aimed at identification of problems concerning energy efficiency of rubber-tracked chassis. The main objective of current investigation is to improve the energy efficiency. To do so a comprehensive optimisation process is to be carried out.

Within the following article, a classification of aforementioned problems will be discussed. Research facilities in laboratory of DORMVE and exemplary results, which have already been obtained, will be also presented.

Keywords: *trackled vehicle, rubber track, rubbert belt, motion resistance, internal motion resistance, energy-efficiency, tractive efficiency*

1. Introduction

The invention of rubber tracks and belts can be claimed as a milestone in tracked vehicle development history. The advantages of rubber tracks and belts over conventional steel link tracks are obvious. Firstly, pressure distribution between rubber track and the ground is more uniform. Secondly, friction drive, which provides superior uniformity of driving torque transmission, can be applied only in case of chassis equipped with rubber belt. What is more, rubber tracks and belts are more lightweight, if compared with steel link tracks. Smaller mass contributes to improved overall performance of rubber-tracked vehicle, mainly defined by higher acceleration and shorter braking distance. Eventually, vehicles fitted with rubber tracks and belts can be driven over paved roads without causing any damage to the road surface.

In spite of numerous advantages, many issues concerning rubber tracks and belts have not been resolved yet. That is why a lot of attention is still payed for research and development of rubber tracks and belts. Nowadays, improvement of vehicle energy efficiency is a common objective in automotive, off-road machine and vehicle engineering. According to initial, unpublished research conducted by The Department of Off-Road Machine and Vehicle Engineering (DORMVE) overall internal resistance of tracked chassis might exceed rolling resistance of conventional pneumatic tire by up to 10 times. Thus, an urgent need to improve the energy efficiency of rubber-tracked chassis exists.

2. Research strategy

Answering the need outlined above, DORMVE conceived a comprehensive research strategy that is aimed at improvement of energy efficiency of vehicles fitted with rubber tracks and belts (Fig. 1). Said objective is to be achieved by means of optimization of tracked chassis design, application of mechatronic chassis control and passive or active systems for track – ground pressure distribution shaping.

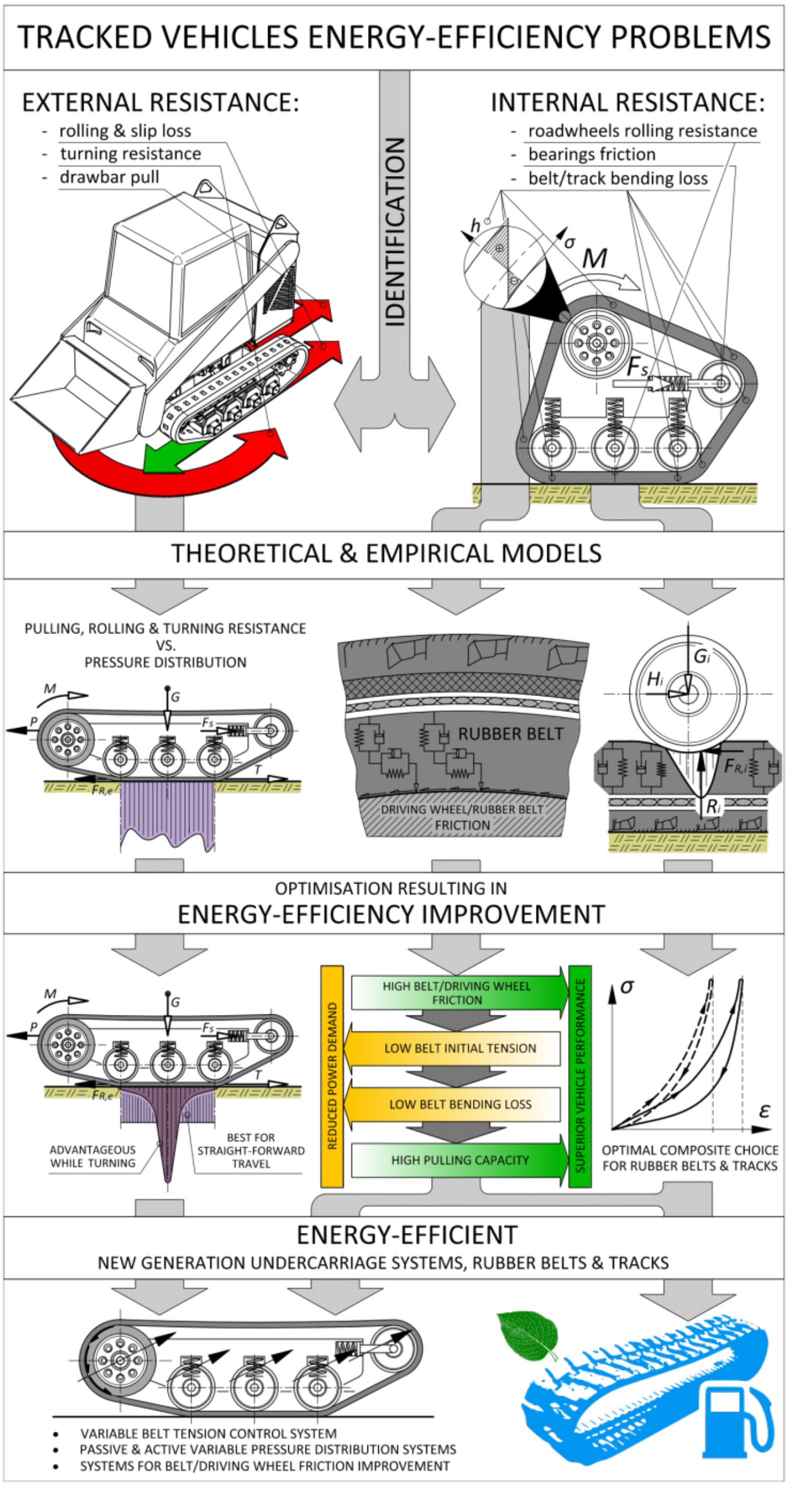

Fig. 1. Research strategy of The Department of Off-Road Machine and Vehicle Engineering pertaining to tracked vehicles energy efficiency improvement

The first crucial goal of DORMVE research and development works is to reduce the internal resistance of rubber-tracked chassis. It might be achieved by decrease in:

- track or belt bending resistance,
- rolling resistance of rollers over rubber track or belt,
- resistance due to interaction between sprocket and rubber track,
- bearings friction torque.

According to research, which has already been carried out by DORMVE, the most severe energy loss is related to two first causes listed above.

Long-standing research and development experience of DORMVE lead to conclusion that decrease in internal resistance can be obtained by both: proper design and maintenance of tracked vehicles. More specifically, tractive efficiency of vehicles of this type might be improved by:

- application of tracks and belts having relatively small mechanical hysteresis,
- decrease in track/belt initial tension,
- increase in friction coefficient between driving wheel and rubber belt, which is essential in case of drive systems with friction torque transmission and reduced initial belt tension,
- increase in uniformity of pressure distribution in roller – rubber track contact (see Fig. 6),
- appropriate choice of rollers and sprocket diameter.

The second objective included in DORMVE research strategy is to decrease external motion resistance of rubber-tracked vehicles. Theoretical considerations [6] and research carried out by DORMVE [1] indicate that significant efficiency improvements can be achieved in this field by suitable adjustment of pressure distribution in track – ground contact. In case of straightforward travel uniform pressure distribution results in small motion resistance. On the other hand, so as to reduce the turning resistance, the pressure distribution shall be non-uniform. In such a case, the area where maximum pressure value shall preferably occur is defined by instant centre of rotation of the vehicle.

DORMVE research led to numerous observations and conclusions, which brought many useful tips for designers of new generation work machines. What is more, they play significant role in elaboration of control criteria for active, intelligent tracked chassis systems. Actually, they have been utilized by DORMVE, so as to design a hybrid, friction/positive drive system with automatically adjustable belt tension, which has been developed in cooperation with German companies INTERTRACTOR, IAMT and IBAF [2].

Rubber track of the hybrid drive system is designed in such a way, that it can be driven either by means of friction between drive wheel rubber lagging and track surface or with use of positive drive sprocket. In basic operation mode, driving torque is transmitted by friction. The belt tension is automatically adjusted to momentary driving force demand defined by external motion resistance, including drawbar pull, grade resistance etc. In extremely harsh conditions, i.e. when soli debris cover the drive wheel lagging preventing the wheel from propelling the belt, positive drive is temporarily engaged. DORMVE still conducts research and development works concerning similar drive systems.

3. Exemplary results – road wheels rolling resistance

Reliable equations describing relationship between rolling resistance of road wheels (rollers) over rubber track or belt with respect to vertical load applied are hardly available. On the other hand, a theoretical formula describing indentation resistance of the conveyor belt, i.e. resistance caused by the roller indentation in the viscous – elastic belt surface, has been developed by Gładysiewicz [4]. Assuming uniform pressure distribution in roller – conveyor belt contact surface, the indentation resistance is as follows:

$$F_{r,i} = A \cdot G_i^{4/3}\,, \tag{1}$$

where:
$F_{r,I}$ – resistance caused by the roller indentation in the belt surface, [N],
G_i – overall vertical force acting at the roller, [N],
A – coefficient defined by roller dimensions and viscous – elastic properties of conveyor belt $[N^{-1/3}]$.

However, equation (1) does not describe the issue of road wheels rolling resistance over rubber tracks in comprehensive way, which is due to a number of design differences. Firstly, rubber tracks are usually thicker than conveyor belts. Moreover, tracks are typically fitted with guide lugs arranged on the inner surface of the track. Consequently, if side force acts at the track, e.g. when vehicle operates on inclined or uneven surface, the rollers touch the lugs, which actually prevent the track form coming off the undercarriage, but also completely changes roller – track interaction regime.

Said differences can be noted on the basis of experiments conducted in laboratory of DORMVE. Test stand shown in Fig. 2 was involved in the investigation.

The main subassembly of the test stand is a measurement plate that enables simultaneously measure three components of reaction force acting at the road wheel being under investigation. The components are vertical and lateral force acting at the roller – G_i and F_y respectively – and longitudinal force $F_{r,i}$, which represents rolling resistance.

A sample of rubber track or belt is attached to the upper horizontal surface of the plate. Before measurement starts, the sample of track and the roller touch each other as the latter is loaded by means of gravity force acting at a horizontal arm of the test stand. So as to vary the load, additional weights might be easily attached to the arm. Side force acting at the roller depends on misalignment of the track sample with respect to the axis of symmetry of the roller. The misalignment can be easily adjusted. During every single measurement, the measurement plate moves in longitudinal direction of the stand. It is being propelled with constant speed by means of a hydraulic cylinder.

Exemplary results shown in Fig. 3. and Fig. 4. refer to experiments conducted with use of a road wheel of crawler compact dumper IHIMER Carry 107 and 180x72x37 rubber track, which is recommended for said vehicle. Two different load cases have been considered within the article.

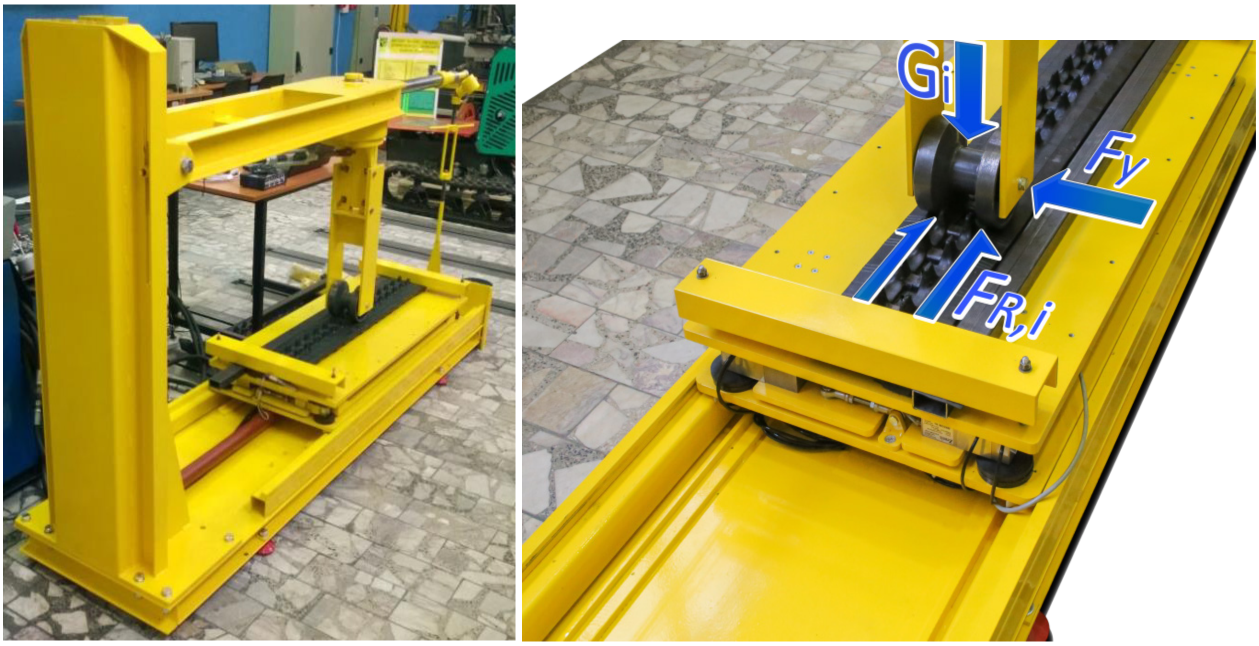

Fig. 2. Test stand in research laboratory of DROMVE at University of Technology Wroclaw for investigation of rolling resistance $F_{R,i}$ between roller and rubber track in relation with vertical G_i and lateral F_y force

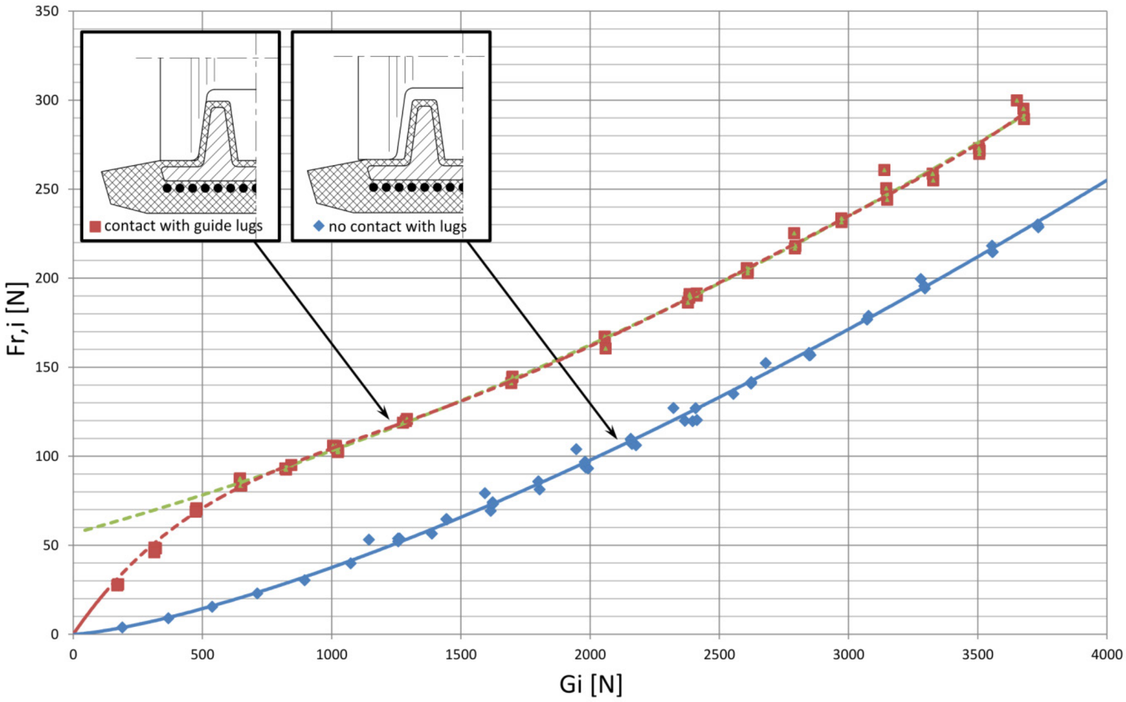

Fig. 3. Exemplary results of roller rolling resistance, while rolling over rubber track – a relationship between rolling resistance force and vertical load

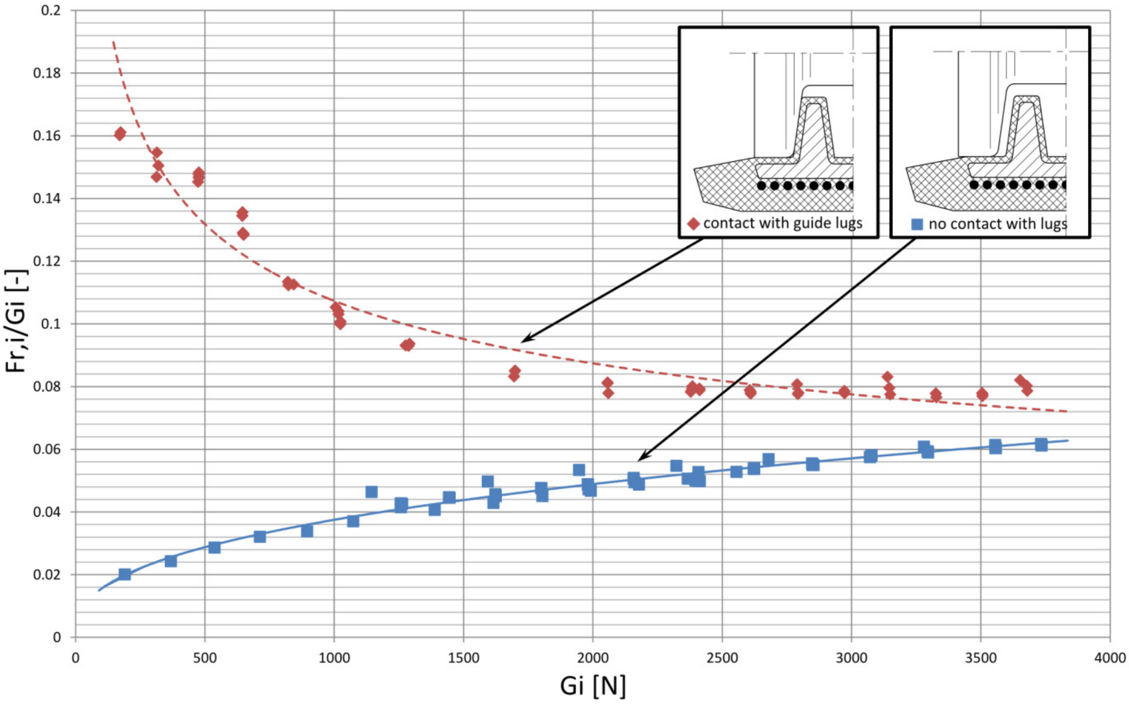

Fig. 4. Exemplary results of roller rolling resistance, while rolling over rubber track: rolling resistance coefficient in relation with vertical load

During initial trials, axes of symmetry of track and roller coincided with each other, so that no contact between roller and guide lugs occurred. In other words, side force acting at the track equalled zero. In such a case, relationship between rolling resistance and vertical load (Fig. 3, solid curve) was as follows:

$$F_{R,i} \propto G_i^{1.38}. \tag{2}$$

The exponent obtained empirically equals 1.38, which is close to theoretical value 4/3. Empirical relationship (2) stays in good agreement with theoretical equation (1). Eventually one can conclude that in the first considered load case rolling resistance was generally due to rubber mechanical hysteresis. Since hard, steel roller was indented in soft, viscous – elastic, rubber track, friction between polymer chains within the rubber volume occurred resulting in heat generation, i.e. energy dissipation.

In the second load case, the track was realigned in such a way, that the inner surface of roller touched guide lugs and, consequently, average side force of about F_y = 325 N was exerted. According to Fig. 3. and Fig. 4. significant increase in rolling resistance was encountered. For vertical load of 500 … 1500 N, which is typical load range for IHIMER Carry 107 crawler rollers, the increase was exceptionally severe. Rolling resistance inclined by up to 5 times in comparison with corresponding results obtained for pure rolling case. Indeed, such a situation is caused by sliding friction between inner roller surface and guide lugs. Dominant role of sliding friction can be distinguished by the shape of a curve representing relationship between rolling resistance coefficient and vertical load (Fig. 4, dashed curve). The rolling resistance coefficient decreases with increasing load, which is also typically observed for hard bodies slid over soft, rubbery materials. What is more the exponent of the trend line equation is within -1/3 … -1/9 range, which stays in agreement with references [3, 5, 7].

Fig. 5. An example of a work machine standing on artificially created, uneven surface

Work machines usually operate on inclined or uneven surfaces (Fig. 5) which results in rollers – guide lugs contact as well as non-uniformity of pressure distribution in roller – track contact surface. Within the article, the influence of non-uniformity of pressure distribution has been estimated computationally. In order to do so, a semi-empirical formula derived from equation (2) has been elaborated and appropriate calculations were performed. According to the calculations, non-uniformity of pressure distribution caused by 4.5^{O} roller rotation axis tilt might lead to rolling resistance increase by up to 30% (Fig. 6.), which is relatively high value. Obtained computational results are yet to be verified with use of the test stand shown above (Fig. 2).

4. Summary

The Division of Off-Road Machine and Vehicle Engineering conducts comprehensive research and development works aimed at significant improvement of energy efficiency of vehicles fitted with rubber tracks. The goal is to be achieved by decrease of both internal (for example, track/belt bending or road wheels rolling resistance) and external motion resistance (especially turning resistance).

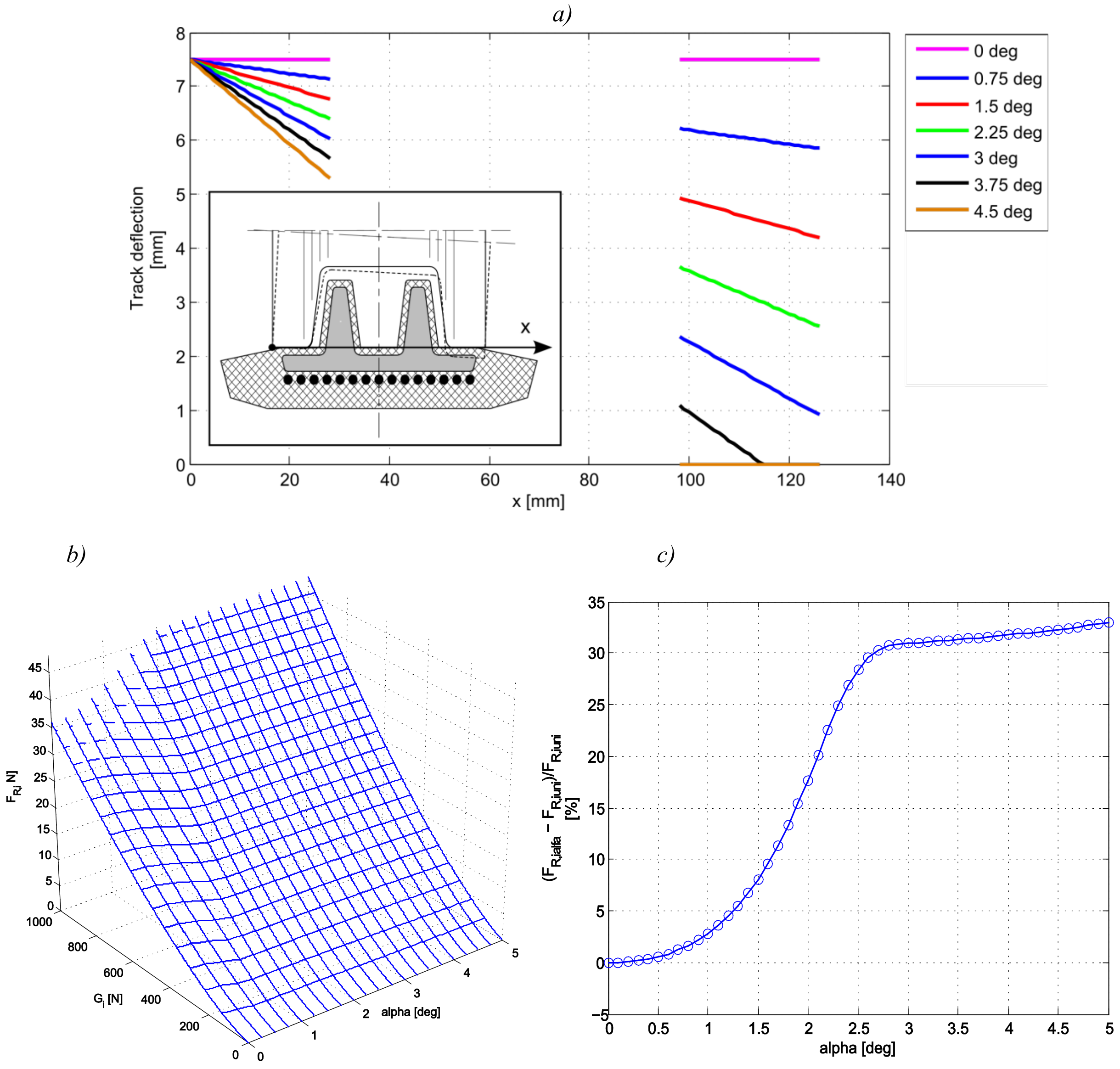

Fig. 6. Hypothetic influence of non-parallelism between roller axis of rotation and surface of rubber track on: a) pressure distribution in roller – rubber track/belt contact area, b, c) overall rolling resistance of roller over the track

According to the investigation pertaining to rolling resistance of road wheels over rubber tracks performed in laboratory of DORMVE, which has been presented within the following article, equations known from the theory of belt conveyors are not sufficient to calculate internal rolling resistance of the tracked vehicle rollers. They can be utilized, if no contact between roller and guide lugs assumption is made. However, work machines usually operate on inclined or uneven surface resulting in both: sliding friction between rollers and guide lugs as well as non-uniformity of pressure distribution in roller – track contact surface. According to presented results, the overall rolling resistance of rollers might increase by up to 5 times due to interaction between roller and guide lugs, when compared with pure rolling case. Moreover, initial computations indicate that even small non-parallelism between roller rotation axis and rubber track surface might result in additional energy loss (increase up to 30% for roller rotation axis tilt of 4.5°). The former issue has been confirmed by means of experiment. The latter is yet to be verified. Nevertheless, the problems outlined here shall be taken into account by tracked vehicle designers during overall power demand calculations. They also bring new ideas for improvement of energy efficiency of tracked vehicles.

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