STUDY ON THE DEVELOPMENT OF AN ADAPTIVE TIRE FOR AGRICULTURAL TRAILERS

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***Abstract**: In this paper was developed a theoretical study, underpinning a solution which can be patented, for an adaptive tire, different from the conventional one, which provides, on arable soil, the advantages of a larger contact surface, with quite uniform pressure distribution in the contact patch, such as for rubber belt track. On public roads, this tire is capable to adapt so that the area of contact patch to be minimum and rolling resistance to be minimum. In tire construction is provided a piezoelectric material, which ensures the required energy to power a pressure sensor, located inside the tire and which monitors tire air pressure. Although the estimated cost of achieving such a tire is significantly higher compared to conventional tires, especially if tire production is not of large series, results obtained by simulation and numeric analysis using Finite Element Method are encouraging and they justify the need of such adaptive tire for agricultural trailers.*

***Key words:** wheel, tire, agricultural land vehicle, agricultural trailer, contact area, FEM.*

INTRODUCTION

Agricultural trailers are technical equipments widely used, which can work in aggregate with agricultural tractors, harvesters or trucks. These trailers (Fig. 1) are designed to transport agricultural products (fruits, vegetables, cereals, flour, etc.), biomass, amendments, chemical fertilizers, agricultural machinery and equipments, etc. Traditionally, agricultural trailers are equipped with standard tires (Fig. 2). Since agricultural trailers must operate on agricultural lands, as well as on roads and public roads requires that their tires have the capacity to adapt to these specific conditions.

In this context, in recent years, there have been a number of studies and ideas, some of them patented, about the possibility to develop some adaptive tires for agricultural land vehicles, and particularly for agricultural trailers [1, 3, 4, 6]. There were developed tires whose footprint shape is controlled and adapted depending on weight per wheel [6]. Also, there were realized and patented some active and adaptive systems for tires, which comprises a tire and an active material configured to alter at least one characteristic of the tire in response to at least one condition [4].

***Fig. 1.** Monoax agricultural trailer TR2000*

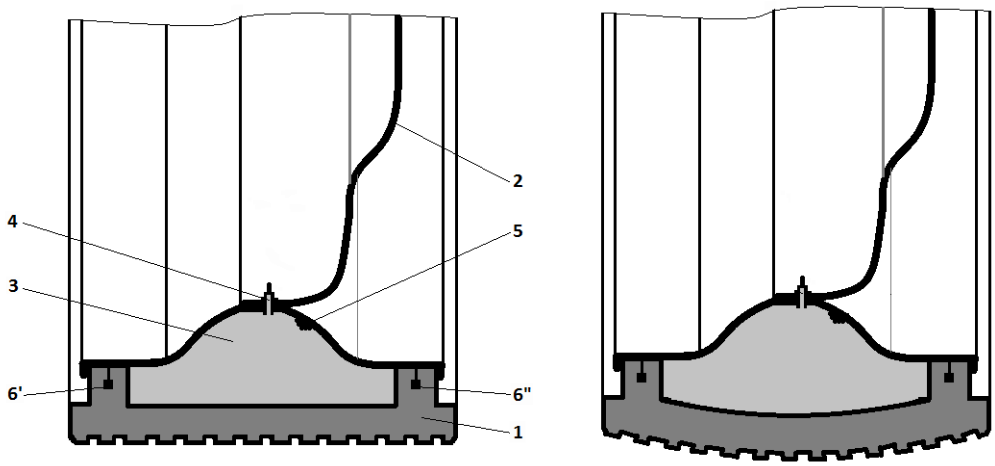
***Fig. 2.** Agr. tire 10.00/75-15.3 12PR*

Even more recently (2011) was patented a dynamic tire-pressure sensor, a control unit, and a built-in air compressor. The pressure sensor can be mounted on a wheel rim associated with a tire for detecting a tire pressure with respect to each wheel [3]. The built-in compressor mounted on the wheel compresses air through an electronic valve from a reservoir to the tire when the tire pressure detected by the pressure sensor is below a predetermined value. The control unit regulates the sensed air pressure from the sensor and controls the operations of the compressor.

There are also worth appreciated the ideas patented in 2008, referring to a tire monitor who includes a first device having at least one piezoelectric matrix element, and a first sensing layer that includes at least one rectifier and a processor element [8]. The first device is capable of sensing a deflection in a layer of material, and is capable of processing the sensed deflection. This first device is capable of wirelessly transmitting an indication on a condition of the material.

Data on soil behavior at the interaction with tires of agricultural vehicles are found in a variety of well known papers (Gill and Vandenberg, 1968), (Koolen and Kuipers, 1983), (Mohseninmanesh and Ward, 2007), (Upadhyaya and Wulfsohn, 1990), (Wulfsohn, 2009).

In this paper, we propose a patentable solution of an adaptive tire to equip agricultural trailers, tire which would have the possibility to modify the surface of contact patch depending on the nature of the rolling track. Thus, for rolling on the road, the surface of contact patch would be as small as possible (high air pressure in the tire) (Figure 3.b), and for rolling on arable land, surface of contact patch would be as large as possible so that the pressure applied on the soil would be as small as possible (reduced air pressure in the tire) (Figure 3.a). Adaptive tire (Figure 3) consists of the tread (1) formed of a thick layer of rubber, disk (2), chamber with adjustable air pressure (3), valve connected to the compressed air supply system (4), pressure sensor (5), piezoelectric materials (6' and 6") which generate the electric voltage required for operation of pressure sensors and for transmitting data to the central system.



a) b)

Fig. 3. *Adaptive tire for agricultural trailer*

MATERIAL AND METHODS

The analysis was developed for the tire in Figure 3 using finite element method. The model of interaction between the adaptive tire and agricultural soil is presented in Figure 4. The tire is made of rubber, which is generally considered to be a non-linear, incompressible or nearly incompressible, hyper-elastic material, which often experiences very large deformations upon loading [7]. The element selected for analysing the rubber material was HYPER185, which was used in conjunction with the two-term Mooney-Rivlin material model [7]. Quick Field Students v5.6 program was used to analyze the plane model of tires section in „plane strain" mode.

The input parameters for the constitutive model of the agricultural soil are [7]: cohesion of soil (c): 18.12 kPa; internal friction angle of soil (φ): 30°; soil density (γ_w): 1270 kg/m^3; Poisson's ratio υ_S: 0.329; Young's modulus E: 3000 kPa

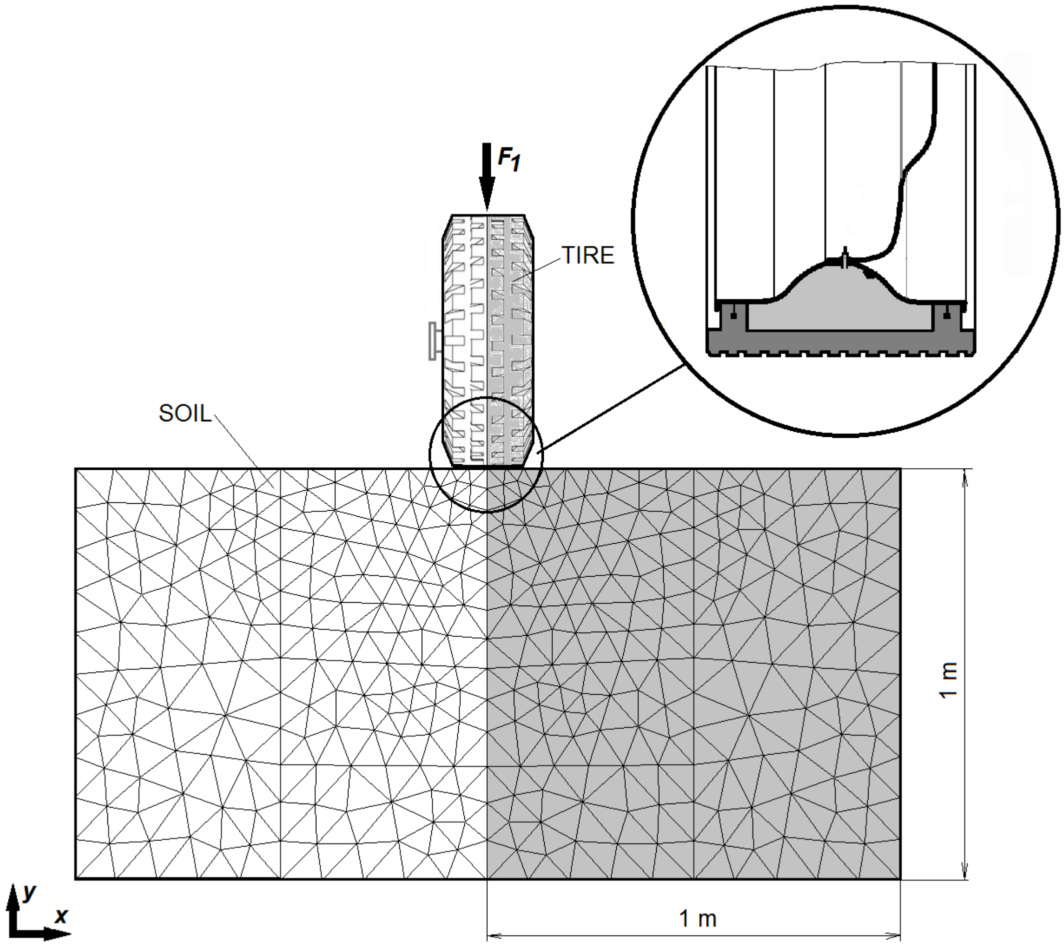


Fig. 4. *Analysis model for the adaptive tire-soil interaction*

For the analysis of stress in the adaptive tire and in the agricultural soil using finite element method, were taken into account the geometrical symmetry and the load presented by the model of interaction (Figure 3), and thus was adopted a “half” model. There were considered two different situations. First, the tire is inflated at high pressure (3 bar), specific to rolling on road, and secondly, the adaptive tire is inflated at small pressure (1 bar), specific to rolling on agricultural soil. In both situations, was analyzed the behavior of the tire under these conditions, and also the behavior of agricultural soil at the interaction with the adaptive tire.

RESULTS AND DISCUSSION

Figure 5 presents the distribution of equivalent stresses by Von Mises criterion in the adaptive tire in the contact area with the rolling track for the two situations (for the two pressures). There is also traced the outline of the tire after the strain, due to the application of the external load. Figure 6 presents the distribution of total displacement in the tire in the same section and the graphical variation of those displacements on the outline of the analyzed axis-symmetric model. Figures 5 and 6 allow the identification of the proper position of the piezoelectric material inserted in the tread or in the carcass of the adaptive tire. Figure 7 presents a comparative analysis of the distribution of equivalent stresses in agricultural soil at the interaction with the adaptive tire for the two situations of tire operation (namely, high pressure and small pressure).

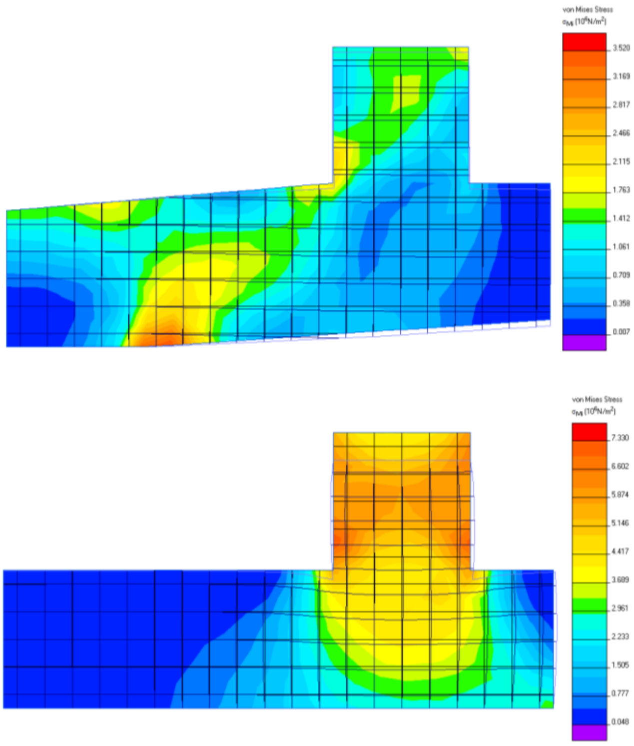


Fig. 5. *Distribution of equivalent stresses in the adaptive tirein the contact area with the rolling track*

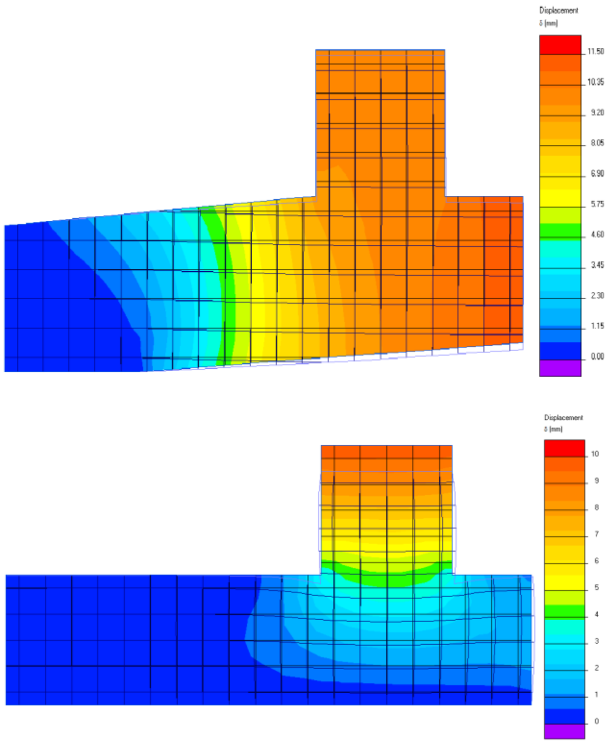


Fig. 6. *Distribution of total displacements in the adaptive tire in the contact area with the rolling track*

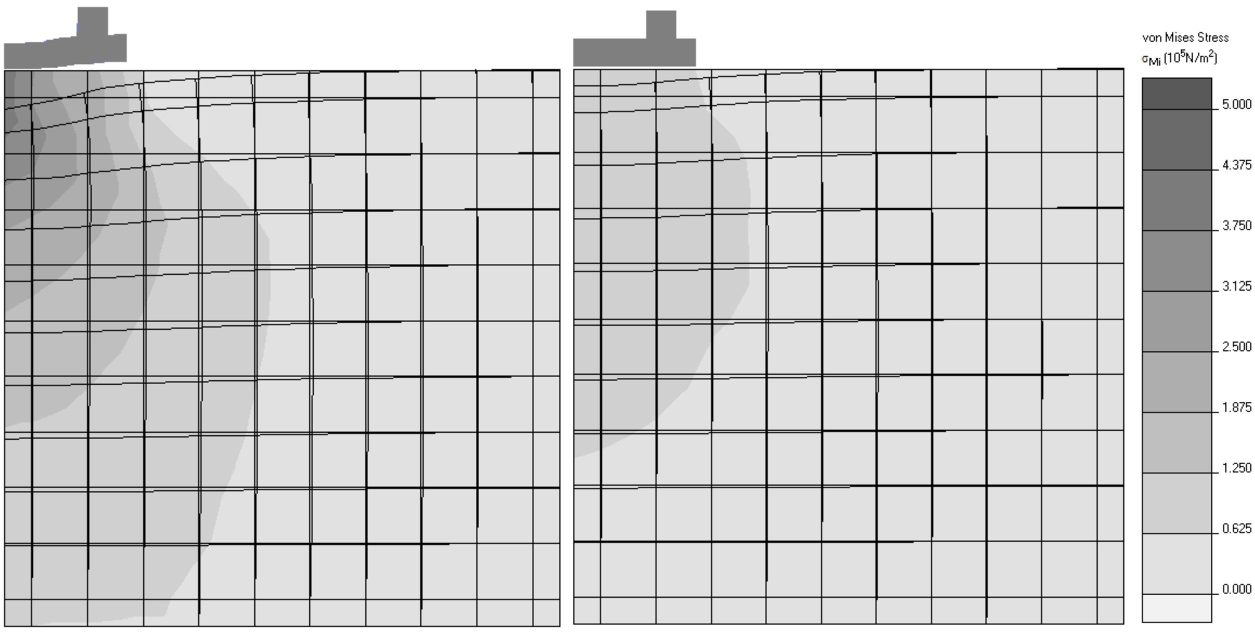


Fig. 7. *Comparative analysis of distribution of equivalent stresses in agricultural soil for the two situations of adaptive tire operation*

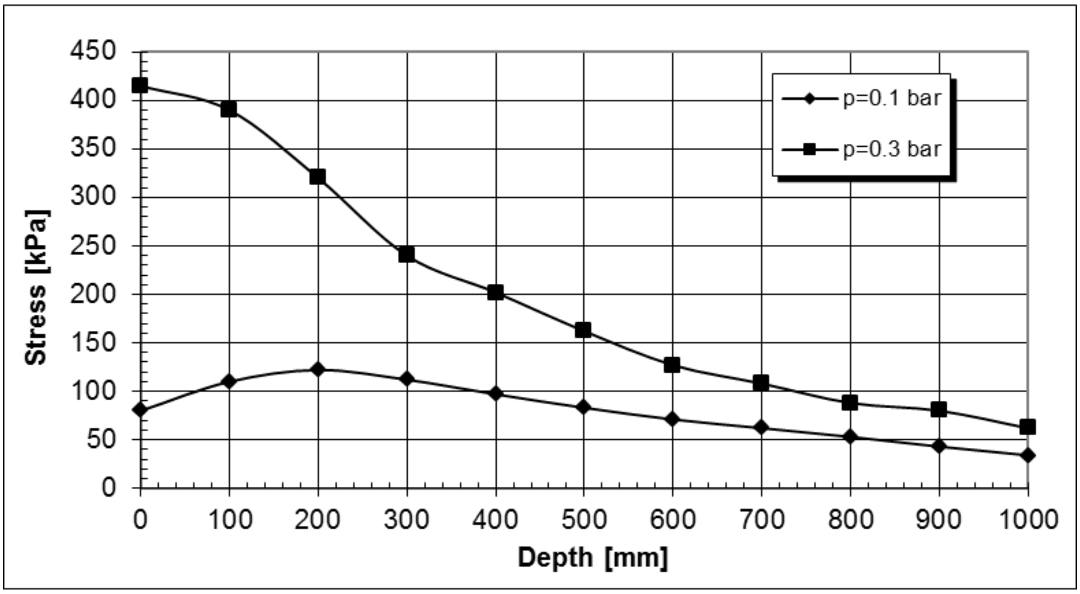


Fig. 8. *Graphical variation of equivalent stresses in agricultural soil with depth, for the two situations of adaptive tire operation*

Figure 8 shows the graphical variation of the equivalent stresses with depth in agricultural soil on the vertical axis of symmetry of interaction model tire-soil. From figures 7 and 8 it can be noticed that in the case when the adaptive tire provides a larger contact surface with the soil, in the second case the equivalent stresses in the soil are more reduced and the probability of artificial soil compaction is considerably reduced. If tire air pressure is high, corresponding to easily rolling on the road, and the vehicle enters on arable land, equivalent stresses in soil are much higher and they facilitate the apparition of artificial soil compaction phenomena.

CONCLUSIONS AND FUTURE WORK

1. From the bibliographic study and from the numerical analysis using finite element method it results more obvious that the action that is required to be done in the field of agricultural tires, considering the diversity of rolling track conditions, is to design and implement technical solutions of adaptive tires.
2. Considerable deformations and equivalent stresses of tire carcass (Fig. 6 and 7) allow the adoption of some technical solutions which require the insertion of piezoelectric materials in the tire carcass, which would produce the electric energy required to supply the pressure sensor from the tire and also wireless data transmission to the central system mounted on the tractor.
3. Although the cost of such adaptive tire is higher than the cost of classic tire, the positive effects related to the phenomena of artificial soil compaction and also to the reduction of energy consumption for proper rolling on roads and public roads justifies the implementation of such technical solutions of tires to equip agricultural vehicles.

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