

# Adaptive Tyre for Agricultural Trailer



## Agriculture

**KEYWORDS :** finite element method, tyre, trailer, contact area

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### ABSTRACT

*In this paper was developed a theoretical study, underpinning a solution which can be patented, for an adaptive tyre, 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 tyre is capable to adapt so that the area of contact patch to be minimum and rolling resistance to be minimum. Although the estimated cost of achieving such a tyre is significantly higher compared to conventional tyres, especially if tyre 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 tyre for agricultural trailers.*

### INTRODUCTION

Agricultural trailers are technical equipment 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 equipment, etc. Traditionally, agricultural trailers are equipped with standard tyres (Fig. 2). Since agricultural trailers must operate on agricultural lands, as well as on roads and public roads requires that their tyres have the capacity to adapt to these specific conditions.



Figure 1: Monoax agricultural trailer TR2000



Figure 2: Agricultural tyre 10.00/75-15.3 12PR

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 tyres for agricultural land vehicles, and particularly for agricultural trailers [1, 3, 4, 6]. There were developed tyres 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 tyres, which comprises a tyre and an active material configured to alter at least one characteristic of the tyre in response to at least one condition [4].

Even more recently (2011) was patented a dynamic tyre-pres-

sure sensor, a control unit, and a built-in air compressor. The pressure sensor can be mounted on a wheel rim associated with a tyre for detecting a tyre 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 tyre when the tyre 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 tyre 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 behaviour at the interaction with tyres 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, I propose a patentable solution of an adaptive tyre to equip agricultural trailers, tyre 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 tyre) (Figure 3 a), and for rolling on arable land

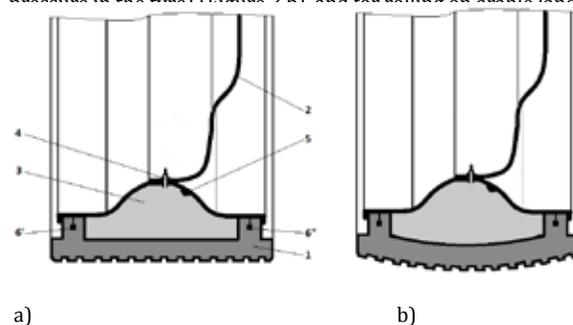
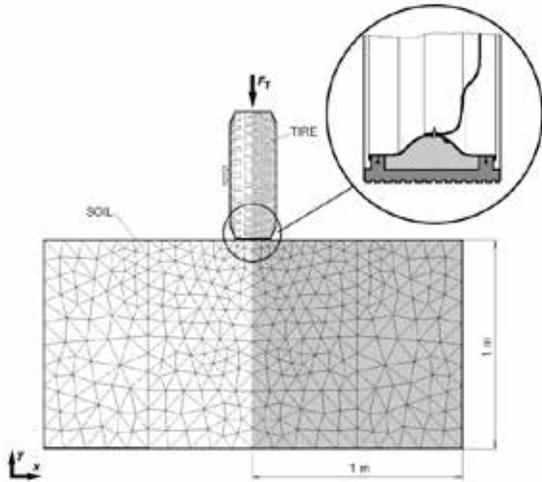


Figure 3: crumb rubber in cracker mill

### MATERIAL AND METHODS

The analysis was developed for the tyre in Figure 3 using finite element method. The model of interaction between the adaptive tyre and agricultural soil is presented in Figure 4. The tyre 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 analyse the plane model of tyres 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 ( $\phi$ ): 30o; soil density ( $\gamma_w$ ): 1270 kg/m<sup>3</sup>; Poisson's ratio  $\nu_s$ : 0.329; Young's modulus  $E$ : 3000 kPa.

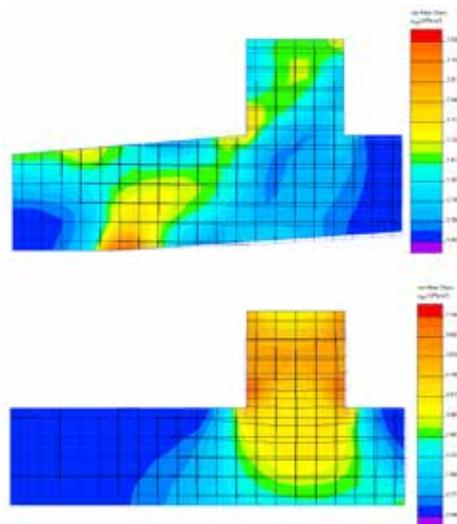


**Figure 4: Analysis model for the adaptive tyre-soil interaction**

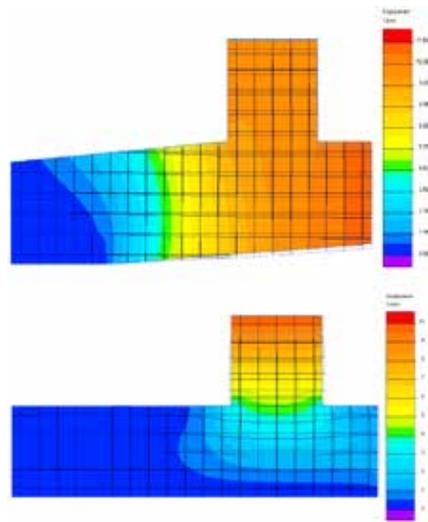
For the analysis of stress in the adaptive tyre and in the agricultural soil using finite element method, were taken into account the geometrical symmetry and the load presented by the model of interaction (Figure 3), and thus was adopted a "half" model. There were considered two different situations.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

**RESULTS AND DISCUSSION**

Figure 5 presents the distribution of equivalent stresses by Von Mises criterion in the adaptive tyre in the contact area with the rolling track for the two situations (for the two pressures). There is also traced the outline of the tyre after the strain, due to the application of the external load. Figure 6 presents the distribution of total displacement in the tyre in the same section and the graphical variation of those displacements on the outline of the analysed axis-symmetric model.



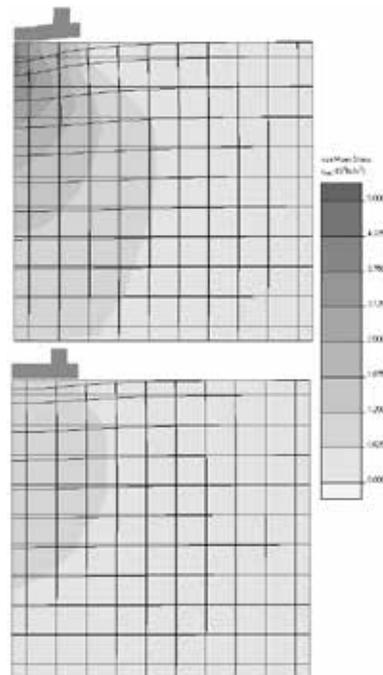
**Figure 5: Distribution of equivalent stresses in the adaptive tyre in the contact area with the rolling track**



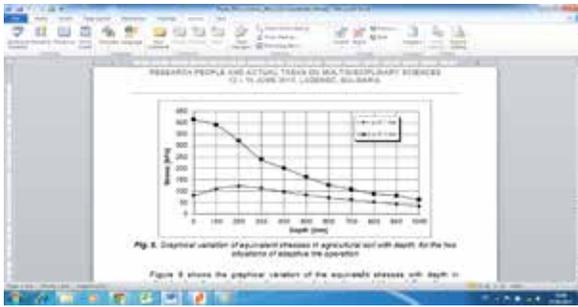
**Figure 6: Distribution of total displacements in the adaptive tyre in the contact area with the rolling track**

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 tyre. Figure 7 presents a comparative analysis of the distribution of equivalent stresses in agricultural soil at the interaction with the adaptive tyre for the two situations of tyre operation (namely, high pressure and small pressure).

Figure 8 shows the graphical variation of the equivalent stresses with depth in agricultural soil on the vertical axis of symmetry of interaction model tyre-soil. From figures 7 and 8 it can be noticed that in the case when the adaptive tyre 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 tyre 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.



**Figure 7: Comparative analysis of distribution of equivalent stresses in agricultural soil for the two situations of adaptive tyre operation**



**Figure 8: Graphical variation of equivalent stresses in agricultural soil with depth, for the two situations of adaptive tyre operation**

## CONCLUSIONS AND FUTURE WORK

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 tyres, considering the diversity of rolling track conditions, is to design and implement technical solutions of adaptive tyres. Considerable deformations and equivalent stresses of tyre carcass (Fig. 6 and 7) allow the adoption of some technical solutions which require the insertion of piezoelectric materials in the tyre carcass, which would produce the electric energy required to supply the pressure sensor from the tyre and also wireless data transmission to the central system mounted on the tractor. Although the cost of such adaptive tyre is higher than the cost of classic tyre, 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 tyres to equip agricultural vehicles.

## REFERENCE

- [1]Burns, A. R. (2007), "Tyre." United States Patent, No. 20070215259 A1. | [2]Gill, W. R., Vandenberg, G. E. (1968), "Soil Dynamics in Tillage and Traction." U.S.A. Department of Agriculture, Handbook 316, USA, Washington D.C. | [3]Hinojosa, Jr. J., Coronado, A. C. (2011), "Automatic tyre pressure control and monitoring system and method." United States Patent, No. 20110203710 A1. | [4]Jongsma, J., Theuss, H. (2012), "Active and adaptive tyre systems". United States Patent, No. 8,234,918 B2. | [5]Koolen, A. J., Kuipers, H. (1983), "Agricultural Soil Mechanics." Advanced Series in Agricultural Sciences, Vol. 13. Springer, Heidelberg, pg. 241. | [6]Manne, P. M., et al. (2003), "Pneumatic tyre having a load dependent adaptive footprint shape." United States Patent, No. 6,564,839 B1. | [7]Mohsenmanesh, A., Ward, S. M., (2007), "Tractor tyre-road and tyre-soil interactions model using ANSYS." Biosystems Engineering Research Review. University College Dublin, 33-137. | [8]Ofaz, O. (2008), "Piezoelectric tyre sensor and method." United States Patent, No. 7,343,787 B2. | [9]Sornioti, A., Vigliani, A. (2006), "Numerical models for tyres simulation." International Conference on Tribology AITC-AIT, 20-22 September, Parma, Italy. | [10]Upadhyaya, S. K., Wulfsohn, D., (1990), "Relationship between Tyre Deflection Characteristics and 2-D Tyre Contact Area." Transactions of ASAE, Vol. 33(1), 25-30. | [11]Walker, P., (1996), "Agricultural tyres and wheel assemblies therefore." United States Patent, No. 5,533,793. | [12]Wulfsohn, D., (2009), "Soil-Tyre Contact Area." Advances in Soil Dynamics. ASABE, Vol. 3, pg. 59-84.