Automatic control of air pressure in tires as a factor of safety improvement of wheeled vehicle operation in agricultural sector

R Shkrabak¹, A Kalugin² and I Starunova³

¹Department of safety of technological processes and production, Saint-Petersburg State Agrarian University, 2, Peterburgskoe shosse Street, Saint-Petersburg, 196601, Russian Federation
²Center of Intellectual Property, The South Urals Chamber of Commerce and Industry, 56, Soni Krivoy Street, Chelyabinsk, 454080, Russian Federation
³Faculty of Engineering and Technology, South Ural State Agrarian University, 75, Lenina prospekt Street, Chelyabinsk, 454080, Russian Federation

²E-mail: starfruitworks@gmail.com

Abstract. The article is devoted to the problem of automatic modes of tire pressure regulation in transport vehicles used generally in agriculture where there are a lot of roads performing in very bad condition with mud. Almost all kind of wheeled vehicles could be fitted with air pressure regulation systems. Limits of tire pressure usually regulated by manufacturer so any kind of engineering modifications of tire systems should work in that limits strictly bordered by manufacturer of vehicle and tires. The presented article contains engineering based and practical orientated way to improve drive safety and operator working conditions. Each type of road has such characteristics as safety speed, angle of rollover etc. The authors propose mathematical model of regulation process on the basis of the above mentioned factors of road and vehicle functioning. In the process of modern construction of vehicles the way of module upgrades of existing vehicles becomes more and more popular. In this regard the authors try to propose one of the compromise universal solution for the problem of automatic tire pressure control and regulation.

1. Introduction
In the conditions of industrial manufacture and agriculture the wheeled vehicles operate due to the interaction of a pneumatic wheeled running gear with a support surface [1-4]. It is found that up to 25% of pneumatic tires fail prematurely (90% of them fail because of the violation of air pressure norms inside tires). It is accompanied by overheating, tire fabric lamination, local blistering, cracks, etc. About 95-98 % of all wheeled vehicles (cars, tractors, trailers, complete harvesters, etc.) operate with a deviation from the recommended norms of air pressure inside tires (the deviation is 15-60% of the norm). The manufacturing plants are recommended to allow the following deviation of air pressure from the norm:
- for motor vehicles – not more than 0.1 kg/cm² (0.01 MPa);
- for load carrying vehicles and tractors – not more than 0.2 kg/cm² (0.02 MPa);
- Pressure decrease in tires by 0.5 kg/cm\(^2\) causes the increase in the fuel consumption rate by 4.5 \%, while the decrease by 1.0 kg/cm\(^2\) – by 10-12 \% (on solid roads) [5, 6].

The area of tire contact with the rolling surface decreases, and this, in its turn, causes the decrease in commercial transport exploitation possibility on the surfaces with a low bearing capacity, which increases their propensity to dangerous skidding on slippery roads (Figure 1).

![Figure 1](image1)

**Figure 1.** Dependence of the contact area (S) on the air pressure in the tire (P): 1 – \(G_k = 3,000 \text{ kg}\); 2 – \(G_k = 2,000 \text{ kg}\); 3 – \(G_k = 1500 \text{ kg}\); 4 – \(G_k = 1000 \text{ kg}\).

The above mentioned fact makes it possible to conclude that at decreased and increased air pressure values in pneumatic tires, their dynamic and economic properties of vehicles significantly decrease which causes the growth of the net cost of transporting and the risk of road traffic accident occurrence.

According to the points of problem of safe and rational tire exploitation there are some modern technical features and systems used in vehicle constructions. We would try to observe the most “fresh” and actual technical solutions in that area. Basically we could classify them by the working principle on two large categories: air pressure control systems and inflating (or self-inflating) systems. Thus for example self-inflating perspective constructions of tires are rather widespread as a solution. They are wide presented mostly in the works of Korean groups of scientists [7-9]. So nevertheless technical solutions based on the self-inflating tires by the authors’ opinion couldn’t be used as universal solution for commercial or agricultural transport systems because of their cost and generally car needs a new complete kit of tires. Actually using of self-inflating tires could become a problem when the agricultural operation needs to low pressure in tires on the soft soil for example.

To control the pressure in pneumatic tires, various methods and technical means are widely applied, generally, those produced abroad. One of the leading systems at this market are the solutions consisting of sensor sets continuously connected to the tire valves and transferring data to a board computer (Figures 2-3).

![Figure 2](image2)

**Figure 2.** SAF© TIRE PILOT© system (USA/the Netherlands).
In addition to the obvious advantages of the described methods and the air pressure control systems, their significant flaw is that they are capable of only signaling the change in tire pressure upward or downward. They cannot support the pressure value set by the vehicle operator. The article authors suggest the options of automatic device designs for an automatic maintaining of a normal air pressure in the tires of wheeled transport and technological machines as well as controlling the pressure in the automatic mode [11, 12]. By the way, we try to propose one of the compromise universal solution for the problem of automatic tire pressure control and regulation that could be suitable for commercial and agricultural vehicles.

2. Methods and Materials/Calculations

Such systems are installed both at the Russian agricultural and military cars operating under difficult road conditions and for example some of wheeled tractors. As it is evident, various structures of such systems are applied in motor car and tractor construction, however, the machines, used in agriculture, are generally not equipped with these devices.

However, in this case the equipment for air feed to the tires will require a time-consuming installation and making changes to the vehicle design. Some change in the structure design can make the system suitable for the use in the cars with centralized tire inflation. This will help to make the existing “manual” inflation automatic. When a wheeled vehicle is equipped with high pressure bottles (Figure 5) specially...
installed onto the driving wheel hobs, the system can successfully applied at the vehicles without compressors.

**Figure 5.** General circuit diagram of suggested automatic traction control system: 1 – pneumatic tire; 2 – receiver; 3 – electronic control block (ECB); 4 – air pressure gauges for the driving wheels’ tires; 5 - compressors; 6 – pneumatic tire nipple; 7 – air ducts feeding air to the driving wheels’ tires; 8 – discharge electro-magnet valve of a left driving wheel; 9 – inlet electro-magnet valve of a left driving wheel; 10 - inlet electro-magnet valve of a right driving wheel; 11 - discharge electro-magnet valve of a right driving wheel; 12 – pipes of the air outlet from the tires into atmosphere; 13 - crown for obtaining an input electropulse signal; 14 - inductive contactless sensor.

This system consists of (Figure 5): contactless inductive sensors of angular accelerations (rates) of the driving wheels 14, electronic control block (ECB) 3, including a key system electronic circuit diagram (controller) and the unit of angular acceleration comparator (AAC) of driving wheels, pneumatic compressor 5, receiver 2, crown 13 to gain an input electropulse signal from sensors, air duct 7 for the air intake to the tires of driving wheels, systems of electromagnet valves 8-10 and 11 with the receivers of a controlling contactless signal from the ECB.

**Figure 6.** Principal design diagram of the air outflow process: 1 – tire (as the 2nd reservoir); 2 – receiver (as the 1st reservoir); 3 – inlet EM valve; 4 – discharge EM valve for air (gas) discharge from the tire into the atmosphere; 5 – air duct.

The installation of a traction control system at the driving wheels of a vehicle consists in the preparation of air feed channels in a hob and a wheel semi-axis (Figure 5). The air duct 4 from the receiver is taken through a hole with a proper diameter in the wheel disc and is connected to a mouth piece 3, which is installed into a drilled hob hole by means of a thread connection. In the semi-axis the channel 5 is made by drilling to feed air to a pneumatic tire. In the area of the mouth piece 3 there are sealers 1 for sealing the process of air outflow as well as a locking ring and a distance collar 2 to prevent...
the axial displacement of sealers. We have to note that proposed variant of air pressure control system is based on the results published earlier by our group [10-14] dedicated to the safety of tractor moving modes on sloping/angled surface. Technical part is actually based on patent RU 2589764.

Registering the stoppage of the slipping process on the gauge, resulting from the increase of pressure higher than a normal operating pressure, the operator releases the button while the inlet EM valve of the slipping wheel closes. The system operation stops. To resolve the operation modes for the pressure control system, apply the key provisions of the gas motion theory [15-17]. To do this, apply the principal circuit (Figure 6) (In order to do this, it is necessary to apply …..) and certain assumptions: air (gas) flow takes place without temperature change and heat emission; both reservoirs (the receiver’s tank and the inside volume of a pneumatic tire) are considered to be hard; the compressed air (gas) flow starts after the EM valve opening.

3. Conclusion/Summary

The time of outflow \( t_f \) of air (gas) from the receiver 2 through the valve 3 into the tire 1 can be obtained on the basis of the dependence, previously obtained in the course of the earlier research results [10-14]:

\[
t_f = \frac{1}{\mu \cdot \pi d^2} \int_0^m \frac{1}{\sqrt{2 \cdot \Delta p_m \cdot \rho_{med(m)}}} dm,
\]

where \( t_f \) – time of air (gas) flowing, sec; \( d \) – air duct diameter, m; \( \Delta p_m = p_1 - p_2 \) – pressure difference in reservoirs (depends on the amount of the flowing air mass); \( \rho_{med(m)} \) – average density of air (gas), kg/m\(^3\); \( \Sigma \zeta \) – total of all local hydraulic resistances in the air duct on the side of the pneumatic tire 1 before the air (gas) discharge through the discharge EM valve 4; \( \lambda \) - friction factor along the air duct with the length \( l \) and the diameter \( d \); \( \mu \approx \frac{1}{\sqrt{1 + \Sigma \zeta + \lambda l/d}} \) – discharge coefficient, taking into account the flow (pressure) losses (for the fastener \( \mu \approx 0.7 \); for a circular section it is equal to \( \approx 0.82 \)) [16].

The expression (1) allows justifying the values included in this dependence. To find out the average air (gas) mass flow \( Q_{med} \) for the time of full flowing and the rate of the air (gas) outflow \( V_{(m)} \) in any time moment \( t_{(m)} \), one can use the following equalities [15, 17]:

\[
Q_{med} = \frac{m_c}{t_f},
\]

and

\[
V_{(m)} = \frac{4 \cdot Q_{(m)}}{\rho_{med(m)} \cdot \pi d^2},
\]

where \( Q_{med} \) – average mass flow of air (gas), kg/sec; \( m_c \) – maximum value of the flowing mass, kg; \( V_{(m)} \) – rate of air (gas) flowing, m/sec. The obtained dependence (1) represents a quite basic mathematical model to obtain the main time characteristics of the proposed system and its variants [10-14].

References

[1] Abakumov G V 1999 Correcting Air Pressure in Tires at Vehicle Operation in Winter, Dissertation, Tyumen
[2] Biderman V L 1963 Automobile Tires (Structure, Calculation, Test, Operation) (Moscow: Goskhimizdat) 384 p.
[3] Gorshkov Yu G 2003 *Increasing Efficiency of System Functioning “Differential - Pneumatic Wheeled Running Gear - Bearing Surface” of Mobile Agricultural Vehicles: Monograph* (Chelyabinsk) 207 p.

[4] Boikov V P 1988 *Tires for Tractors and Agricultural Vehicles* (Moscow: Agropromizdat) 240 p.

[5] Balabin I V 1963 *Automobile and Tractor Wheels* (Chelyabinsk: Book house) 335 p.

[6] Putin V A 1968 *Automobile Wheels with Ribbed Tires. (Structure, Research Results, Operation Peculiarities)* (Chelyabinsk, South Ural Book House) 161 p.

[7] Lee C H, Han M J, Park T W 2019 *Int. J Automot. Technol.* 20(297) https://doi.org/10.1007/s12239-019-0029-4

[8] Kim M J, Park T W, Hwang I K 2017 *Int. J Automot. Technol.* 18(973) https://doi.org/10.1007/s12239-017-0095-4

[9] Hong S J and Lee H G 2010 An experimental study of tire safety and economical efficiency with respect to inflation pressure. *Trans. Korean Society of Automotive Eng.* 18(1) 8–13

[10] Gorshkov Y G, Starunova I N, Kalugin A A et al. (2019) Automatic control of air pressure in tires as a way to provide safe movement of wheeled vehicles on slopes. *J. Phys.: Conf. Ser.* 1177 012004 https://doi.org/10.1088/1742-6596/1177/1/012004

[11] Gorshkov Yu G, Chetyrkin Yu B, Starunova I N, Kalugin A A 2013 *Increasing Efficiency of Mobile Vehicles and Improving Work Conditions of Operators in Agricultural Complex: Monograph* (Chelyabinsk: ChGAA) 557 p.

[12] Gorshkov Yu G, Dmitriyev M S, Starunova I N 2010 *Increasing Efficiency of Transport&Technological Processes and Improving Work Conditions of Agricultural Complex Workers due to Engineering&Technical Devices: Monograph* (Chelyabinsk: ChGAA) 291 p.

[13] Gorshkov Yu G, Starunova I N, Kalugin A A 2014 Automatic Control of Air Pressure in Tires at Vehicle Operation at Slopes. *Technics in Agriculture*. 1 13-15

[14] Gorshkov Yu G, Starunova I N, Kalugin A A, Bakunin V V 2014 Justification of Time Necessary for Control of Air Pressure in Tires at Vehicle Motion Along Slope *Scientific Review*. 4 116–122

[15] Idelchik I Ye 1992 *Study Guide on Hydraulic Resistances* (Moscow: Mashinostroyeniye) 672 p.

[16] Kirillin V A 2008 *Technical Thermodynamics: Manual for Higher Education Institutions* (Moscow: MEI Publishing house) 496 p.

[17] Chugayev R R 1982 *Hydraulics: Manual for Higher Education Institutions* (Leningrad: Energoizdat) 672 p.