Automatic control of air pressure in tires as a way to provide safe movement of wheeled vehicles on slopes

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Abstract. The present article deals with the problem of ensuring safe movement of wheeled vehicles on the surfaces with complicated profile. The cause of this problem is that the current engineering solutions to ensure safe movement of wheeled vehicles on slopes have got some technical and technological disadvantages, which reduces both safety and utilization efficiency. To solve this problem, we offer to introduce the system of automatic air control in tires which will lead to increase of efficiency and safety of wheeled vehicles working on slopes. The offered automatic monitoring system works from the position of the inclinometer arrow, connected, by means of electronic system with the air pressure increase and decrease in the tires along the sides of a wheeled vehicle. The article is also to discuss some constituent structures of the above-mentioned system and the algorithm of its work, depending on the value of the surface slope angle.

1. Introduction
Mobile wheeled technology and transport vehicles (tractors, trucks and special vehicles, combine harvesters, self-propelled harvesters, etc.) move along various bearing surfaces including ravines, deep grooves, descents and ascents, which can reach the limit values for movement. When these machines overturn, in most cases, people in the cabs die [5, 6]. The existing devices, such as low-clearance and steep-slope tractors, the use of weights, individual wheel drive, roll angle indicators, etc., often do not justify their purpose due to high metal consumption, complexity in manufacturing and high energy costs [5, 8, 10, 12]. Studies have shown that under these driving conditions, safety of wheeled vehicles when working on slopes depends largely on such factors as: speed, angle of inclination, direction of movement of the machine (across the slope, along the slope), the height of the center of gravity (CG), the track width, condition of rolling surface, the tire tread pattern, the air pressure in it, the manufacturer's recommendations on the limiting angles of the static transverse and longitudinal stability of the machines, the air pressure in the tires, etc.) [1, 10, 11]. One of the important factors mentioned is the amount of air pressure in the tires, which influences the wheel radius, the contact area of the tire with the rolling surface, the longitudinal and transverse adhesion coefficients, the fuel consumption, etc. [1-3]. Taking all these in consideration, the authors of the article propose an automatic system for regulating air pressure in tires.
2. Automatic monitoring system of air-pressure control in the tires of wheeled vehicles

When a wheeled vehicle is operating on a slope with an angle of $\alpha$, gravity G is redistributed among the wheels of the left and right sides. In this case, the radii of the left $r_l$ and right $r_p$ wheels change by the amount of $\Delta r_l$ and $\Delta r_p$ respectively (Fig. 1) [3]:

$$r_l = r_{cm} + \Delta r_l,$$
$$r_p = r_{cm} - \Delta r_p,$$  \hspace{1cm} (1)

where $r_{cm}$ – static wheel radius on a hard horizontal surface, at the same pressure in tires $p_{aw}$.

With an increase in the angle of the slope, the point of application of the center of gravity changes from $O \rightarrow O_1$, which leads to a decrease in transverse and directional stability, as well as to a decrease in the coefficient of adhesion of the left side [3, 9, 11].

![Figure 1. Scheme of changing of the vehicle wheels radii on the slope.](image1)

The value ($r_{cm} \pm \Delta r_{w_0}$) is not constant and depends on the air pressure in the tires, the slope angle, redistribution of the weight of the car over the wheels (sides), the mounted and trailed implement, condition of the rolling surface, speed of movement, angle of deviation from straight-line movement and others. It is proposed to solve this problem by reducing $r_l$ and increasing $r_p$ due to automatic regulation $p_{aw}$ (Figure 2) [7].

![Figure 2. Basic scheme of the device and controlling ties of the system of automatic air pressure control in tires 1 – inclinometer; 2 – electronic block of the system control (EBC); 3 – automatic reducers for pumping (reducing) air pressure in tires; 4 – high-pressure cylinders](image2)
Automatic air pressure control in tires (Figure 2) should be made automatically without the wheeled vehicle operator’s participation in the process of movement.

Inclinometer (Figure 3) is designed to measure the angle of incline for the wheeled vehicle while moving across up or down the slope and to transfer information to electronic block of the system control (EBS). The axis of the inclinometer is pressed in the “skeleton” of the tractor. The sleeve is worn on the axis of the pendulum and secured with a special washer against axial displacement. The arrow with the magnet does not move and fixed on the pendulum of the inclinometer. At any movement of the wheeled vehicle, the pendulum with an arrow tends to maintain its original position I. When the vehicle moves at an angle, the moving scale with reed switches deviates relatively to the fixed arrow of the pendulum of an inclinometer. When combining the arrows of the pendulum with a reed switch, the group of contacts of the computer is closed, corresponding to a specific angle of inclination $\alpha$ of the wheeled vehicle; I, II positions - certain angles of inclination, III - at which the $\alpha$ position - the limiting (critical) angle of inclination movement of the wheeled vehicle is very dangerous and must be stopped.

![Figure 3. Basic scheme of inclinometer to measure the inclination angle of the wheeled vehicle: 1 – pendulum axis; 2 – bushing of the inclinometer pendulum; 3 – inclinometer pendulum; 4 – arrow with magnet; 5 – inclinometer scale; 6 – reed switches of the inclinometer](image)

EBC serves to process incoming informative signals from an inclinometer and to activate the control program $p_{in}$. The principle of operation of the gearbox is that after receiving the appropriate signal from the EBS, there is an inlet (outlet) of a certain portion of air (gas) into the tires (from the tire) of the right or left sides of the wheeled vehicle. High pressure cylinders are designed to reserve compressed air (gas) and supply it to the gearbox. Depending on the design features, high-pressure cylinders can be of various shapes and designs. They can be mounted on the wheel disk, located in the spokes of the disk, etc. They can be refueled in the workshops of farms or special points. With a certain refinement of the system, standard equipment (receivers) on machines with pneumatic drive brakes can be used.

The increase and decrease of air pressure in the tires (to the required values) does not occur instantly, but during some relatively short time periods [4]. This can be explained, to some extent, by the constancy of the load (discharge) of the wheels, the angle of the slope, the inertia force, when turning the machine, the length of the path, air resistance in the channels of the device, the speed of the machine, air pressure (gas) in the high-pressure cylinder of the device. (Figure 4) [1].

The control system $p_{in}$ is activated only at fixed points in time when the pendulum and reed switch contacts close. The duration of these points in time depends on the design parameters of the regulator (high pressure cylinder with solenoid valve), air pressure in the tires of wheeled vehicles, sizes of air channels (diameter, length), spring parameters of solenoid valves, values of air friction in the channels pressure, etc. After the pressure control system triggers (the position of inclinometer II or III), it turns
off, and the wheeled vehicle continues to move, overcomes the incline with the offset of the gravity centre G in the safe zone. This ensures a more stable movement of the machine even when the maximum permissible angle of inclination pre-set by the manufacturer [11] is reached.

Figure 4. Schematic diagram of a high-pressure cylinder with an electromagnetic valve for regulating air pressure in tires: 1 - a body of a high-pressure cylinder; 2 - holes for mounting the cylinder to the wheel hub of the car; 3 - body of solenoid valve; 4 - a spring of the electromagnetic valve; 5 - intake valve; 6 - solenoid valve heart; 7 - channel for entry of compressed air (gas) to the air through the solenoid valve; 8 - a cone nut of fastening of the electromagnetic valve in a cylinder; 9 - cylinder filling valve cover; 10 - cylinder filling valve; 11 - air release valve

In case that the wheeled vehicle moves on a rise (descent), the inclinometer must be rotated in the longitudinal direction (on a slope or from a slope). In this case, the $p_{ui}$ regulator, when going uphill, will pump up the rear tires and bleed the air in the front tires; on the descent in reverse action.

3. Algorithm of automatic system air pressure regulation in wheeled car tires when working on slopes

1. Movement of the wheeled vehicle on a horizontal surface:
   - tire pressure complies with the recommendations of the manufacturer;
   - the arrow of the inclinometer is in the first “0” position (Figure 3);
   - control of the system and its automation do not work and are in the “ready” position.

2. Movement of the wheeled vehicle across the slope:
   - depending on the value of the slope angle $\alpha$, the position of the arrow of a tilter approaches the position of the I scale, which is characterized by a relatively low degree of danger in tipping the machine. Therefore, if the arrow of the inclinometer do not reach position II, then the control of the system and its automation do not work and are in the “ready” position.
   - when the arrow of the inclinometer is in position II, the automatic system and its control are included in the work. This opens the automatic device valve and compressed air from a high-pressure cylinder enters the tires (for example: the starboard side of the wheeled vehicle), increasing the radii of the wheels. At the same time, the air pressure in the tires of the left-side wheels is reduced by opening the automatic exhaust valve. As a result, the radii of the left side wheels are reduced. The direction of the center of gravity of the masses of the machine is shifted to a position safer than position III. The automatic system shuts down from work and becomes in the "ready" position. In this case, if the angle
of the slope $\alpha$ does not change in a big direction, then the machine can move for quite a long time across the slope until it reaches a larger angle of slope.

With a further increase in angle $\alpha$, position III - “dangerous” corresponds to the limiting (critical) angle of inclination at which the machine can tip over if its speed exceeds the permissible value or the tire hit a fixed obstacle [2]. Only in this case, the starboard wheels are pumped up to larger values; in the left-side wheels, the air pressure is reduced to smaller values.

It should be noted that the provisions of I, II, III of inclinometer are determined by different in value increase or decrease radii of the wheels of the right and left sides:

$$\Delta r_u = \Delta r_{ul} + \Delta r_{ull} + \Delta r_{ulll}, \quad r_u = r_{cu} + \sum \Delta r_u$$
$$\Delta r_l = \Delta r_{rl} + \Delta r_{rll} + \Delta r_{rlll}, \quad r_l = r_{cl} - \sum \Delta r_l$$

If the arrow of the inclinometer is above position III, the wheeled vehicle should be stopped and measures should be taken to increase its stability.

Conclusion
The proposed system for regulating air pressure in tires allows you to control the position of the center of gravity of the wheeled vehicle when driving on slopes, which ensures the safety of the work of operators and improves their working conditions.

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